T-WAVE GENERATION MECHANISMS

By
ROCKNE H. JOHNSON
and
ROGER A. NORRIS

JANUARY 1970

FINAL REPORT

Prepared for

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HAWAII INSTITUTE OF GEOPHYSICS
UNIVERSITY OF HAWAII
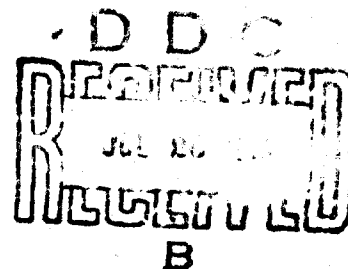
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Contents

ABSTRACT

The transformation of earthquake body waves to $\underline{T}$ waves is as
efficient at deep slopes as at slopes which transect the sofar
axis. Moreover, spectral studies of $\underline{T}$ phase signatures have
shown no basis for distinguishing between the two cases. As
simple downslope propagation is inadequate to explain the
production of $\underline{T}$ waves at deep slopes, that process is relegated a
minor role in favor of scattering from the sea floor as the
dominant mechanism. A slope in the direction of propagation
insures that once energy is scattered in that direction the
probability of its being unfavorably rescattered upon successive
approaches to the sea floor will be less. Scattering near the
sea surface is detectable in the absence of bottom-scattered
$\underline{T}$ waves. Such abyssally generated $\underline{T}$ waves display a distinctly
higher frequency spectrum when originating in subarctic regions
than when originating in lower latitudes. This difference is
ascribed to downward ducting of higher frequency energy from the
subarctic surface channel.

INTRODUCTION

A widely recognized gap in extant hypotheses for the generation of T waves is the explanation of the strong signals received from the East Pacific Rise. There the ocean is too deep to support the production of sofar rays by downslope propagation. The T phases received, however, resemble those generated at shallow slopes much more closely than those generated at abyssal depths (i.e., in close proximity to trenches). A second problem is the observed difference between the spectrum of abyssal T waves generated in the subarctic and that of T waves from lower latitudes. In order to resolve these problems a study has been conducted of sonagrams (intensity level contoured in the frequency-time plane) of T phases from over 400 earthquakes occurring all around the Pacific.

BACKGROUND

Tolstoy and Ewing (1950) recognized the importance of a sloping bottom in the production of T waves. The specific mechanism of multiple reflection between the sea surface and its downsloping bottom (downslope propagation) was first detailed by Milne (1959). Johnson et al. (1963) showed that, for a 10° slope and an acoustic profile typical of the Aleutians, the downslope propagation process would produce sound channel rays only if the rays entered the water at depths of less than about 500 meters. For RSR (refracted surface-reflected) rays this limiting depth is perhaps doubled. Although T waves originating over ocean trenches have been observed, their spectral and time-varying characteristics differ markedly from slope T waves and a generative mechanism involving scattering at the sea surface has been proposed (Johnson et al., 1968). These authors noted, however, that T phases originating along the East Pacific Rise display the low-frequency spectrum of slope T phases, yet the

waves cannot be accounted for by downslope propagation. Cooke
(1967) also recognized this predicament. It is necessary, then,
to modify the hypothesis for slope T-phase generation to include
T phases generated at deeper slopes.

DATA

The data presented in the appendix to this report are
sonagrams made from over 400 earthquake T phases tape-recorded
from sound-channel hydrophones of the Pacific Missile Range at
Oahu, Midway, Wake, and Eniwetok islands. Tapes were ordered for
analysis if the paper-drum recordings from the stations contained
T phases from earthquakes which were identified by the U. S.
Coast and Geodetic Survey (C&GS) preliminary determination of
epicenter cards as being from abyssal regions or from an earthquake
of magnitude 6 or greater. In processing the tapes, every T phase
generated by an earthquake identified by the C&GS was sonagrammed
irrespective of magnitude or region. No attempt was made to
compensate for the response of the hydrophone-cable-amplifier systems,
although their characteristics vary from installation to installation
and systematic spectral differences are thereby introduced.

DEEP-SLOPE T WAVES

A verification that T waves are indeed radiated from deep
slopes is illustrated by a sequence of earthquakes which occurred
off northern Honshu in June 1968. The foci of four of the earthquakes
are shown in Figure 1 as well as the focus of an earthquake farther
offshore. The source data are listed in Table I. Figure 2
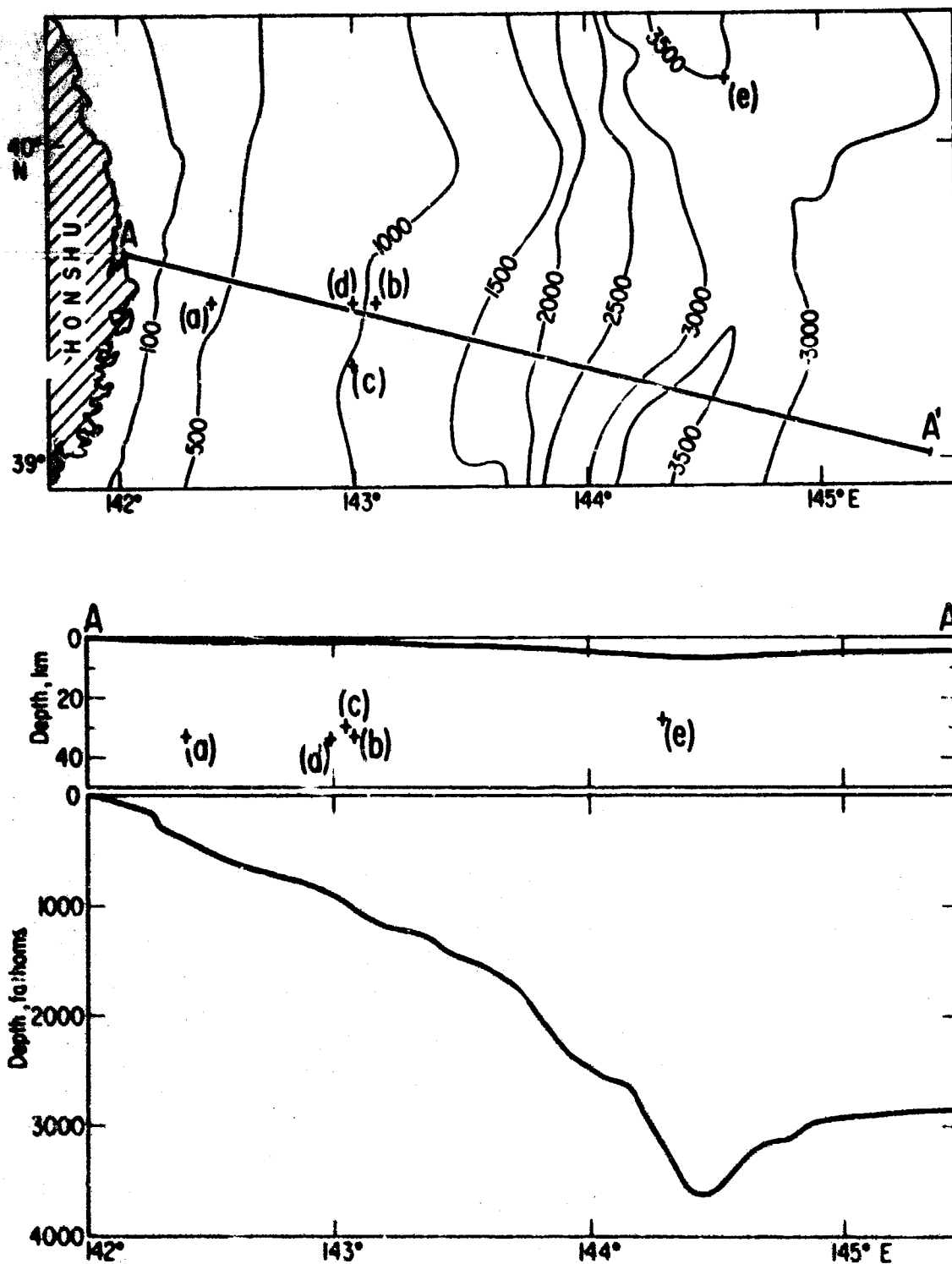presents the sonagrams of the corresponding T phases. (Frequency

Fig. 1. The foci of five earthquakes off northern Honshu shown both in
plan (upper) and elevation (lower). Bottom contours are in fathoms.
Source data are listed in Table I and sonagrams are presented in
Figure 2. The bathymetry along section A-A' is shown both true
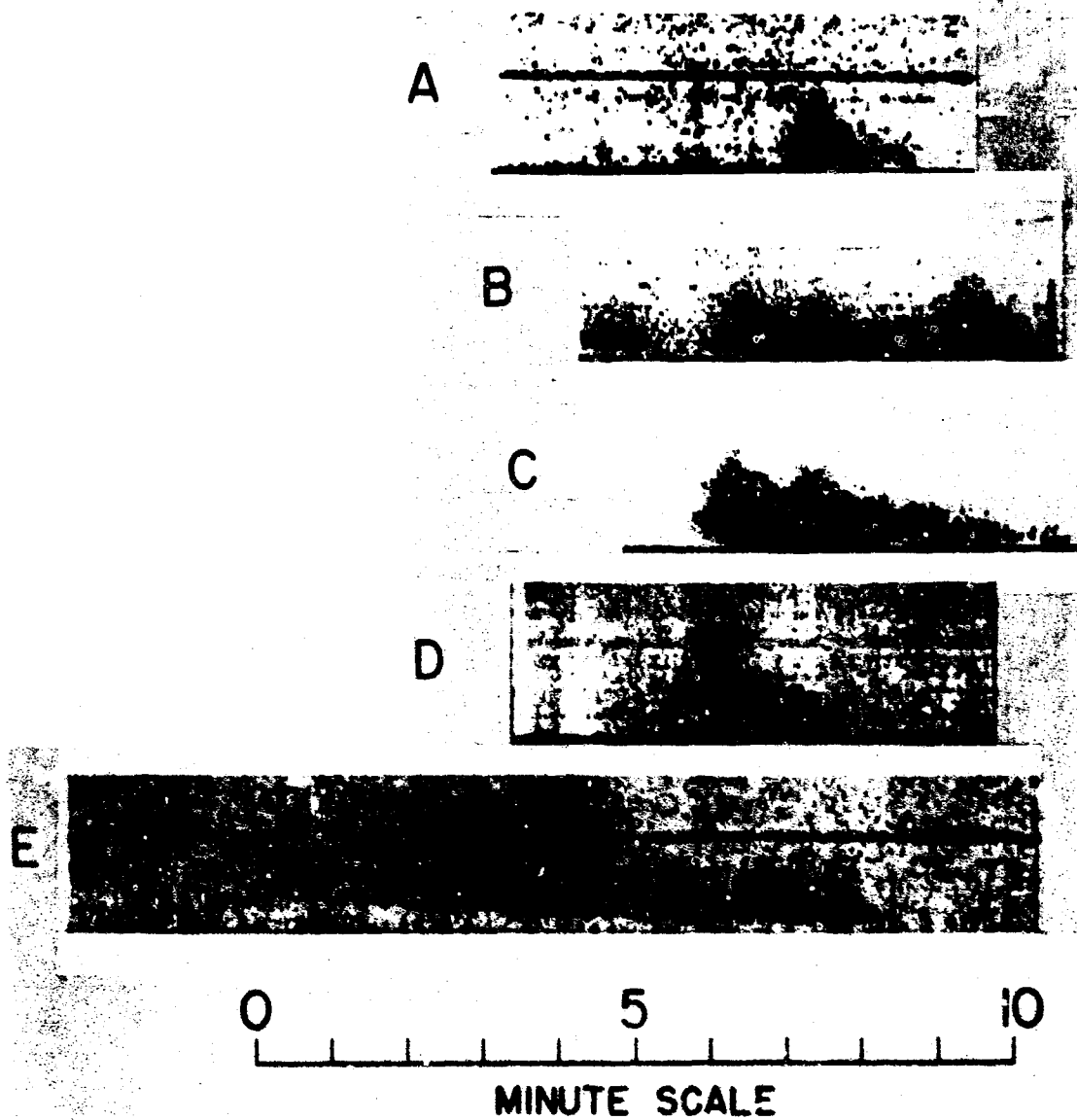scale and with 20X vertical exaggeration.

FIG. 2. Sonagrams of T phases from earthquakes off northern Honshu. Foci are shown in Figure 1 and source data are listed in Table 1. (Frequency range is 0 to 50 hz in these and all other sonagrams.)

Table I. Source Data for Events Shown in Figure 1.

Selected Off-Honshu Earthquakes

Event	Lat., °N	Long., °E	Depth, km	Mag., M_b	Date, d m y	GMT, h m s
a	39.5	1'.2.4	33	4.1	18 Jun 68	13 38 01
b	39.5	143.1	33	4.3	12 Jun 68	17 23 18
c	39.3	143.0	30	5.1	12 Jun 68	15 48 59.5
d	39.5	143.0	34	4.5	26 Jun 68	20 26 19.0
e	40.2	144.6	27	5.0	24 Mar 67	04 11 29.6

range: 0 to 50 hz, bottom to top on all sonagrams in this report.)
Event (a) is characteristic of slope $\underline{T}$ phases while event (e)
generated both an abyssal and a slope $\underline{T}$ phase at a spacing
appropriate for the distance of the epicenter from the continental
shelf.   Likewise, events (b), (c), and (d) also generated two
groups of $\underline{T}$ waves, each of which is appropriately spaced for the

distance of the epicenter from the shelf. In cases (b), (c), and
(d), however, the first group of waves lacks the identifying
characteristics of an abyssal $\underline{T}$ phase, the only notable distinction
from the second group being the inclusion of higher frequencies.
The water depth at epicenters (b), (c), and (d) was about 2000
meters with a bottom slope of one to two degrees. These conditions
are clearly insufficient to produce even RSR rays by downslope
propagation over a smooth bottom (Aubrat, 1963).

In fact, however, continental and island slopes are not
smooth, but are cut by submarine canyons and crossed by fault
scarps which serve to scatter acoustic energy upon initial
refraction into the water as well as during multiple reflection
within the water wedge. This scattering materially reduces the

length of slope required to produce horizontal rays.

The scattering mechanism is equally operable at shallow slopes and must equally cause the production of shallow-slope T waves. The shallow-slope T phases may be slightly stronger at the lower frequencies however, since lon er wavelengths, which are not as readily scattered, can be deflected into horizontal paths by the length of a slope available. The lack of higher frequency energy for the shallow-slope T phases shown in Figure 2 is ascribable to attenuation over the longer ground path. This variation of low-frequency content with water depth was recognized by Duennebier (1968) as a decrease of peak frequency with time over the early portions of slope T phases from the Fox Islands.

Computed sources of slope T phases have been found to form clusters indicative of topographically controlled sites of strong radiation (Johnson and Norris, 1968a; Duennebier and Johnson, 1967). By contrast, abyssal T-phase sources appear to radiate most strongly from the earthquake epicenter. The excitation of a uniform scattering horizon is inferred from the very gradual onset and decay rates of abyssal T waves. The onset and decay rates of deep-slope T waves are practically identical with those of shallow-slope T waves, suggesting a similar topographic control of radiation. The lack of any basis for distinction between the two groups of signals is readily apparent in Figure 3, which contains a selection of sonagrams from earthquakes along the East Pacific Rise as well as a selection of shallow-slope T waves (Table II).

The mechanism and conditions for generation of deep-slope T waves also apply to T waves from the East Pacific Rise. Although here the average slope is much more gradual than at the margins of the Pacific, the topography is characteristically faulted, the faults apparently being in close association with earthquake epicenters. Such fault scarps, then, at once provide the
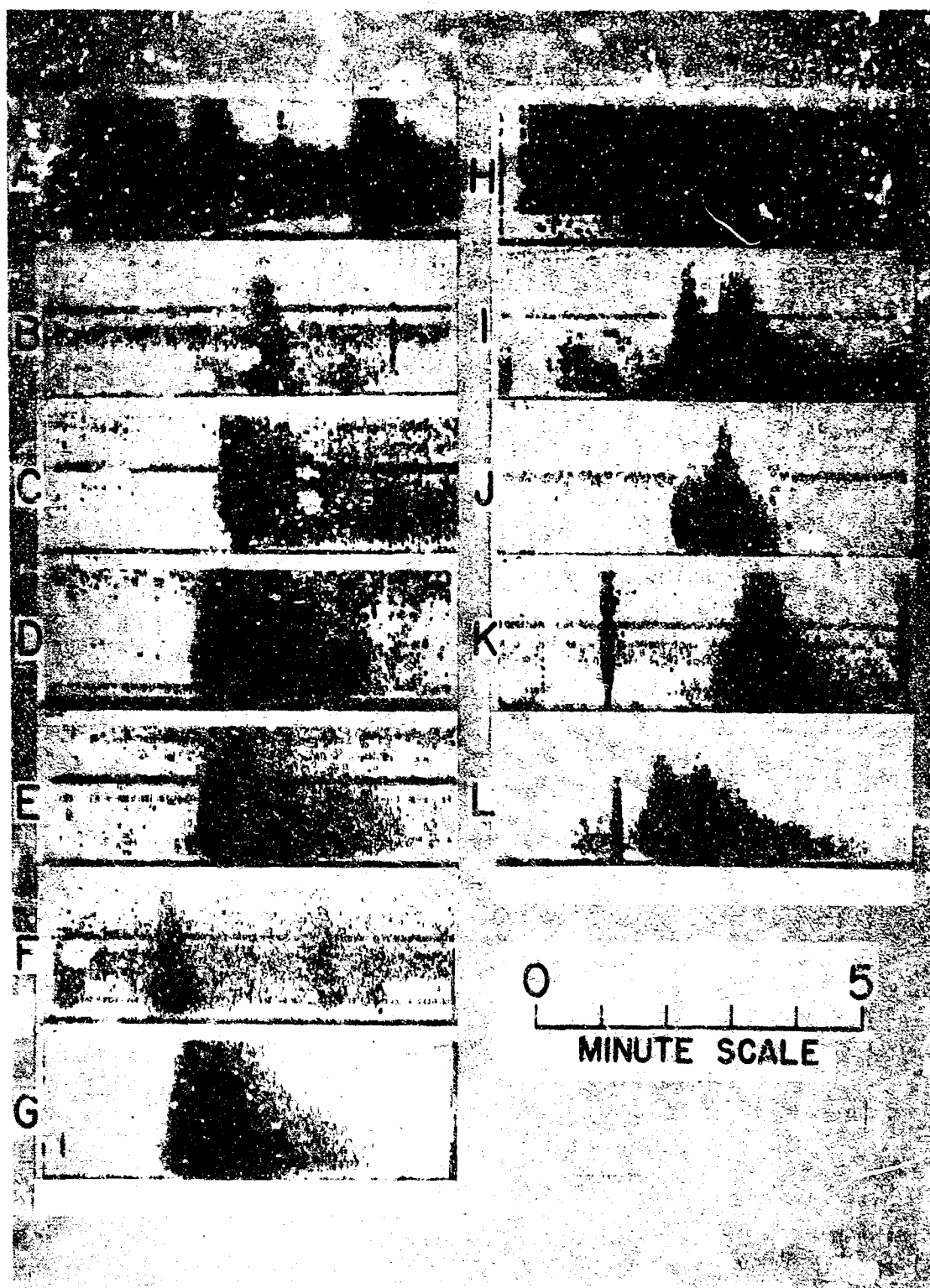
FIG. 3. Selected sonagrams of T phases from the East Pacific Rise (on the left) and selected shallow-slope T phases (on the right). Source data are listed in Table II.

Table II. Source Data for Events Shown in Figure 3.

Selected East Pacific Rise Earthquakes (Fig. 3, left)

Event	Lat.	Long., °W	Depth, km	Mag., M_b	Date, d m y	GMT, h m s
a	44.2N	128.8	33	5.4	28 Dec 67	06 26 15.8
b	42.0N	126.2	33	4.9	26 Sep 67	05 51 11
c	2.6N	101.8	33	4.9	28 Mar 68	12 44 38.0
d	2.1N	101.1	33	4.7	30 Dec 67	02 46 55
e	4.0S	104.1	33	4.5	16 Jun 68	14 01 22
f	32.8S	111.7	33	5.4	29 Dec 66	22 16 22.7
g	54.8S	136.0	33	5.4	9 Sep 67	16 52 01.3

Selected Shallow-Slope T Phases (Fig. 3, right)

Event	Lat.	Long., °W	Depth, km	Mag., M_b	Date, d m y	GMT, h m s
h	40.6N	125.0	33	4.4	17 Jun 68	03 05 44
i	40.5N	124.6	05	5.8	10 Dec 67	12 06 50.3
j	37.0N	121.6	11	5.0	18 Dec 67	17 24 31.9
k	20.0S	70.3	60	4.6	8 Nov 67	10 47 45.3
l	21.5S	70.4	53	5.8	25 Dec 67	10 41 31.6

scattering facets and the localized radiators for deep-slope
T wave generation.

T-phase strength offers no basis for distinguishing between
deep-slope and shallow-slope T phases. T phases from the Gorda
Ridge (Northrop et al., 1968)--which is well below the sofar axis--
are at least as strong, relative to earthquake magnitude, as slope
T phases from the Aleutian Ridge (Johnson and Northrop, 1966;

Johnson and Norris, 1968a). Deep-towed-echosounder profiles of the Gorda Ridge indicate faulted blocks with scarps dipping at 30-degree angles (Atwater and Mudie, 1968). Such rugged terrain probably accounts for strong T-wave generation.

T phases originating along southern portions of the East Pacific Rise are equally as strong as those from the Gorda Ridge. Here the relief along the crest of the rise is more subdued, however earthquake epicenters are found to lie principally along the steep-sided fracture zones which offset the rise (Menard, 1966; Sykes, 1963).

Duennebier (1968), in describing an Eniwetok hydrophone recording of a magnitude 6.2 earthquake under the Mariana Ridge, states that energy was continuously received at the hydrophone from the time of the P phase arrival until after the arrival of the slope T phase from the Mariana Ridge. Strong signals were received at intermediate times, corresponding to P-wave travel to intervening seamounts followed by T-wave travel to the hydrophone. Although, as Duennebier points out, the tops of these seamounts are well below the sofar axis, such steep slopes (Robertson and Kibblewhite, 1966) may be expected to radiate T waves into RSR and off-axis sofar paths with relative efficiency.

Two earthquakes from the North Pacific Basin have their foci (Table III) under the newly discovered Emperor Fracture Zone (Erickson et al., 1970). Here, the bottom is characterized by irregular ridges and troughs with elevations no more than 1 km above the regional level. Since all depths in the epicentral region are greater than the bottom of the sofar channel, only RSR and multiply reflecting rays can be generated by scatter at the sea floor. The T phases recorded at Midway (Figure 4a and b) show the characteristic broad spectrum of such bottom-scattered waves, but in addition they show the gradual onset and decay that is suggestive of a uniform scattering horizon. This effect may be due to the alignment of the topography with the direction to Midway or the
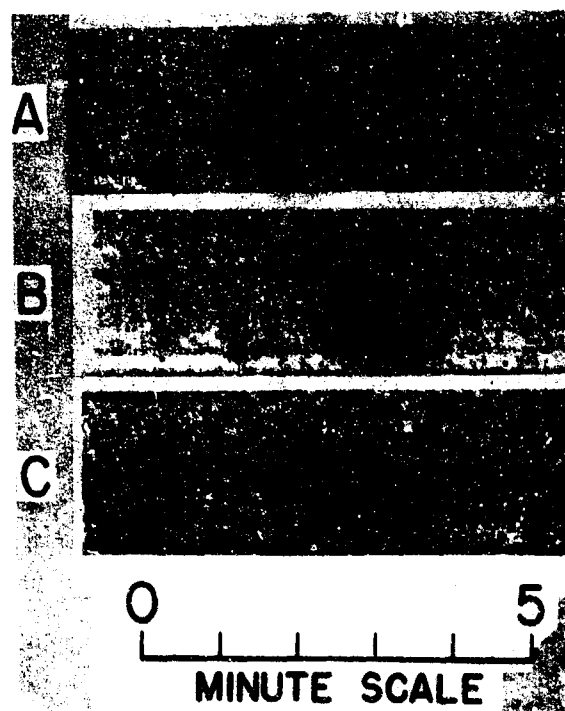
FIG. 4. Sonagrams of T phases from earthquakes under the deep-ocean floor. Source data are listed in Table III.

result of the superposition of near-surface scattered (abyssal) T waves upon bottom-scattered waves.

Table III. Source Data for Events Shown in Figure 4.

Event	Lat.	Long.	Depth, km	Mag., M_b	Date, d m y		GMT, h m s	
a	44.8N	174.5E	39	5.5	28 Apr 68		04 18 15.7	
b	44.8N	174.7E	33	4.3	28 Apr 68		06 23 02	
c	12.0N	130.8W	33	5.3	24 Sep 66		08 57 10.2	

Figure 4c shows another Pacific Basin T phase with its focus (Table III) under the less well-charted ocean floor between Clarion and Clipperton fracture zones. The low strength of this T phase, relative to the earthquake magnitude, suggests a lack of topographic relief in the epicentral region.

PROPAGATION OF DEEP-SLOPE T WAVES

RSR paths exist when the speed of sound in the bottom water is greater than it is at the surface. This condition is easily met in higher latitudes where the surface water is cold; but in the tropical and sub-tropical Pacific, existence of the condition depends strongly on water depth. From about 45°N to 40°S the East Pacific Rise is too shallow to permit RSR propagation. Within this region such sound energy as is scattered clear of a sloping bottom will enter the sofar channel as off-axis rays. At higher latitudes proportionately more energy will be scattered into initially RSR paths. Such paths may become totally refracted sofar paths upon entering regions of warmer surface water.

Unattenuated propagation by totally reflecting paths (normal

mode) is theoretically possible in a constant-depth ocean. However, if bottom scattering is an acceptable mechanism for slope T-wave generation, a continuation of that scattering over the travel path would militate against propagation—by normal mode—to significant distances. The very low frequencies at which sound may be effectively propagated by bottom-reflecting normal mode in the deep ocean are beyond the sensing range of presently installed hydrophones.

In computing T-phase source locations, it has been assumed that the most intense arrival travels at sofar-axis sound speed (Johnson, 1966). As no near-axis sofar rays are generated by the proposed deep-slope T-wave mechanism, a somewhat higher apparent sound speed would be appropriate to such cases. For example, in the vicinity of Midway, the sofar ray which is horizontal at ~ 3000-meter depth has an apparent speed that is 0.3% higher than the speed of the sofar axis ray. Such a difference in speed would produce about an 8-second arrival-time difference over the path from the tropical East Pacific Rise to Midway. This would correspond to a source location difference of .25°. The simple, sharply peaked signature of East Pacific Rise T phases should readily allow the detection of such a discrepancy were the epicenter known with sufficient accuracy. Such is not likely to be the case in this remote region of the Pacific, however.

ABYSSAL T WAVES

Situations where the bottom cannot scatter energy into RSR or sofar paths occur where the ocean floor is level or at a greater depth than adjacent areas in the direction of the receiver. Johnson et al. (1968) detected T waves from such regions in the subarctic Pacific and termed them "abyssally generated". The signals were characterized by very gradual onset, a lack of low frequencies, and

a low strength relative to earthquake magnitude. They usually
appear as the forerunner of a slope-generated T phase (Duennebier,
1968).

For Pacific earthquakes in lower latitudes, the forerunners,
which may commence at the time for direct P-wave arrival, show no
perceptible difference in spectrum from the slope arrivals.
Figure 5 illustrates this contrast between the forerunners of
subarctic and lower latitude T phases (source data listed in Table
IV). As previously noted, the occasional intensification of

Table IV. Source Data for Events Shown in Figure 5.

Event	Lat.	Long.	Depth, km	Mag., M_b	Date, d m y		GMT, h m s	
a	50.6N	171.3W	39	6.5	7 Aug 66		02 13 05.1	
b	44.3N	151.7E	26	5.8	7 Dec 66		17 17 42.0	
c	40.8N	143.2E	07	7.9	16 May 68		00 48 55.4	
d	27.4N	144.3E	40	4.6	6 Feb. 64		08 00 35.0	
e	20.8N	146.3E	43	6.2	10 Feb 66		14 21 10.9	
f	18.4N	146.5E	77	5.0	20 Jan 68		20 06 48.0	
g	7.1S	81.6W	23	6.5	29 Aug 63		15 30 31.4	

signal strength in the lower latitude events may be accounted for
by radiation from intervening seamounts. However, even the
continuous portion of the lower latitude forerunners has essentially
the same frequency distribution as the slope T waves that follow.

The most distinctive acoustic feature of subarctic (and arctic)
waters is the absence of a deep sound channel (Johnson and Norris,
1968b). Although a shallow, subsurface, velocity minimum may
exist in summer, propagation is predominantly RSR. Kutschale (1961)
found that explosion signals which propagated through the Arctic
Ocean exhibited a dispersion of frequencies which was nicely

explained by normal-mode theory. For a given mode, higher frequency energy is concentrated nearer the surface and propagates at a correspondingly lower group velocity.

Upon entering a region with warmer surface water, shallower RSR rays become sofar rays. This ducting of higher frequency energy into the sofar channel, which occurs over paths to the PMR hydrophones from the subarctic but not from the Mariana or southern Japan trenches, may therefore partially explain the spectral differences in abyssal $\underline{T}$ waves.

The appearance of a low-frequency cutoff on sonagrams of many subarctic abyssal $\underline{T}$ phases (Fig. 5) strongly suggests that their initial propagation is confined to a surface layer. According to Kibblewhite and Denham (1965), the minimum duct-depth L for trapping any modes for frequency f is

$$L = 0.54\ c_0\ (f^2 g)^{-1/3}$$

where c_0 is sound speed at the surface and g is a constant gradient of speed. Figure 6 is a graph of this equation for $c_0 = 1460$ m sec^{-1} and $g = 0.014\ sec^{-1}$. If 10 hz is taken as a typical low-cutoff frequency, it is seen that subarctic abyssal $\underline{T}$ waves are ducted within at least the upper 700 meters of water. The absence of lower frequencies must be ascribed to the absence of significant large-dimensioned scatterers at sufficient depth to excite antinodes for sound pressure for lower frequencies. At lower latitudes, scattering in much of this 700-meter layer, as from a rough thermocline, will occur within the sofar channel. Here the interference patterns of normal-mode propagation are not conditioned by a surface boundary and depths of antinodes are indeterminate. This may account for the lower frequencies of $\underline{T}$-phase forerunners from the region of the Mariana and southern Japan trenches, although, alternatively, the abundance of seamounts over the paths from that region may be responsible.

The fact that slope $\underline{T}$ phases from the subarctic contain fre-
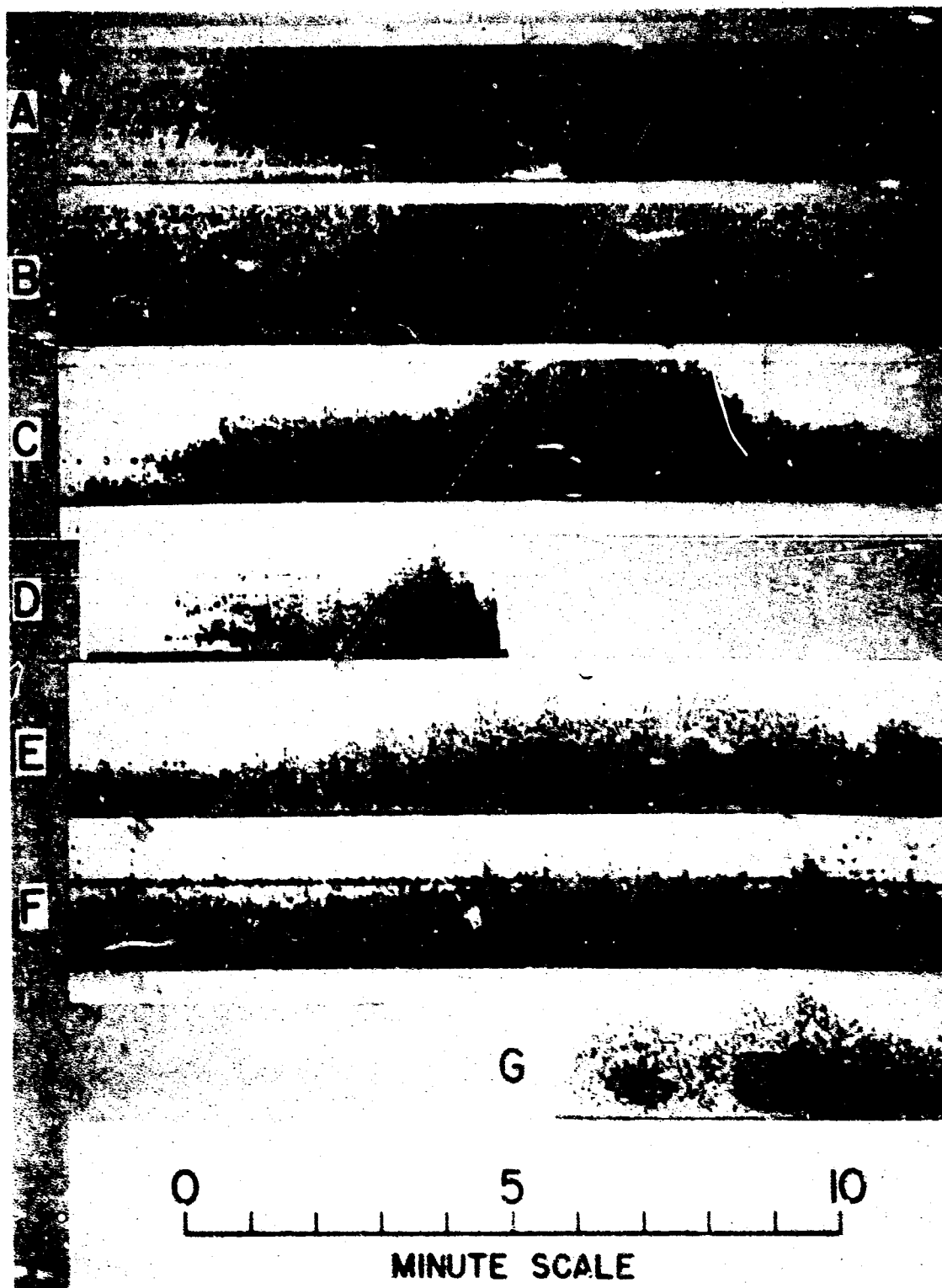
FIG. 7 phases, with abyssal forerunners from the subarctic (A, B, and C) contrasted with those from lower latitudes. Source data are listed in Table IV.
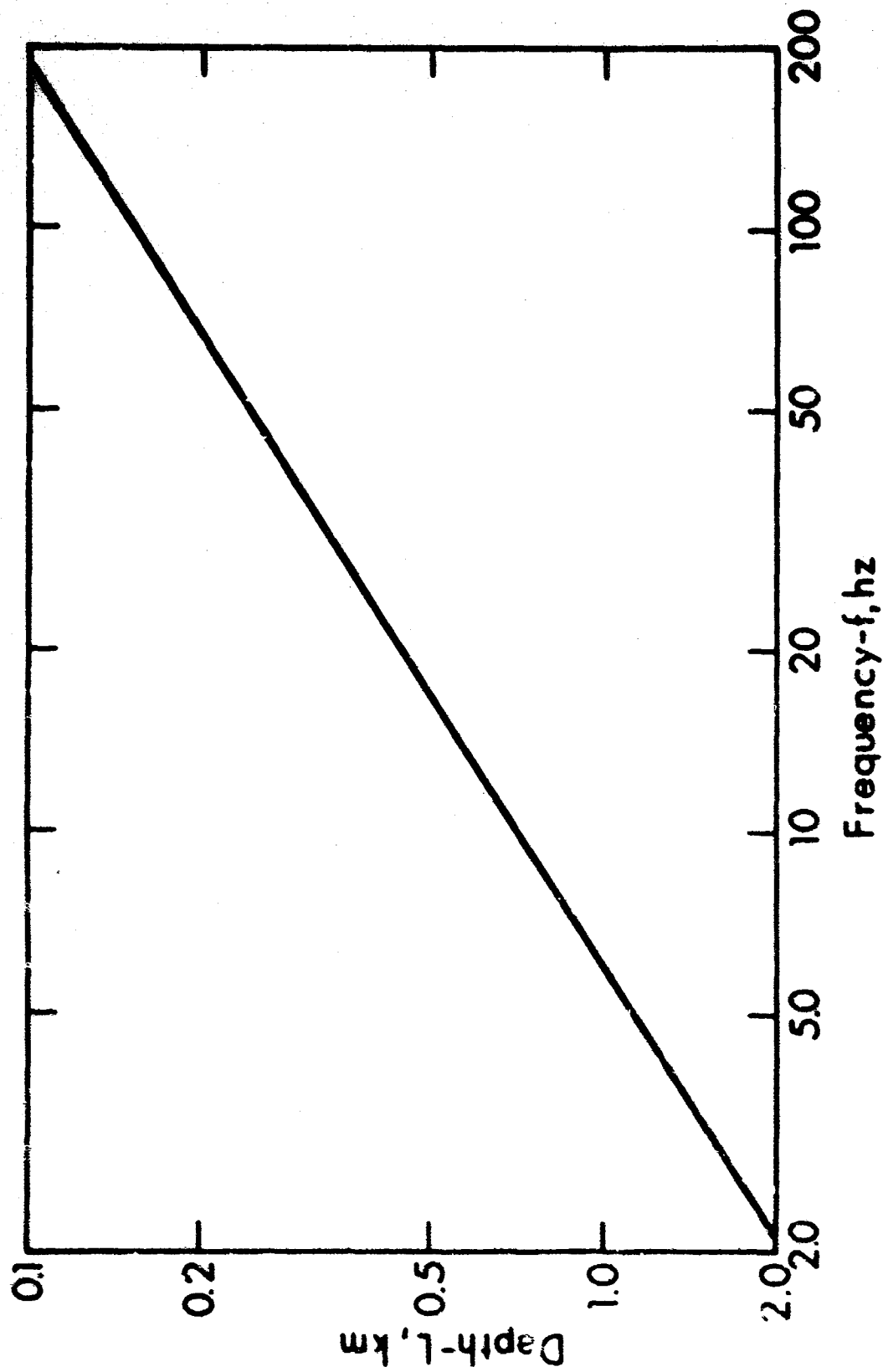
Fig. 6. Graph of the minimum depth of the RSR duct capable of trapping any mode at a given frequency. Sound speed at the surface is 1460 m sec^{-1}, with a constant gradient of 0.014 sec^{-1}.

quencies which are lower than those of their abyssally generated forerunners indicates excitation of RSR normal modes at greater depths. Nearly all of such energy will also be ducted into the sofar channel upon entering regions of warmer surface water.

CONCLUSION

Earthquakes under deep slopes generate T phases as efficiently as earthquakes under shallow slopes. In either case the short onset and decay rates indicate that the T waves are produced at radiators of restricted dimensions. In contrast, abyssal T phases, which are produced in the vicinity of trenches or over the flat ocean floor, show onset and decay rates for which a uniform scattering horizon is indicated. The production of T waves at a sloping bottom is ascribed to scattering from the bottom, either initially or in the course of multiple reflection within the water wedge.

Deep-slope T waves generated within the Central Pacific follow off-axis sofar paths. This hypothesis may be tested by comparing observed and predicted arrival times at Midway, with those at Wake, or at Eniwetok, from accurately located sources along the East Pacific Rise.

Abyssal T waves from the subarctic region are of distinctly higher frequencies than are abyssal T waves from lower latitudes. This difference is ascribed to downward ducting of higher frequency energy from the subarctic surface channel.

ACKNOWLEDGMENTS

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APPENDIX

INDEX MAP

Page numbers are marked beside segments of the bold line
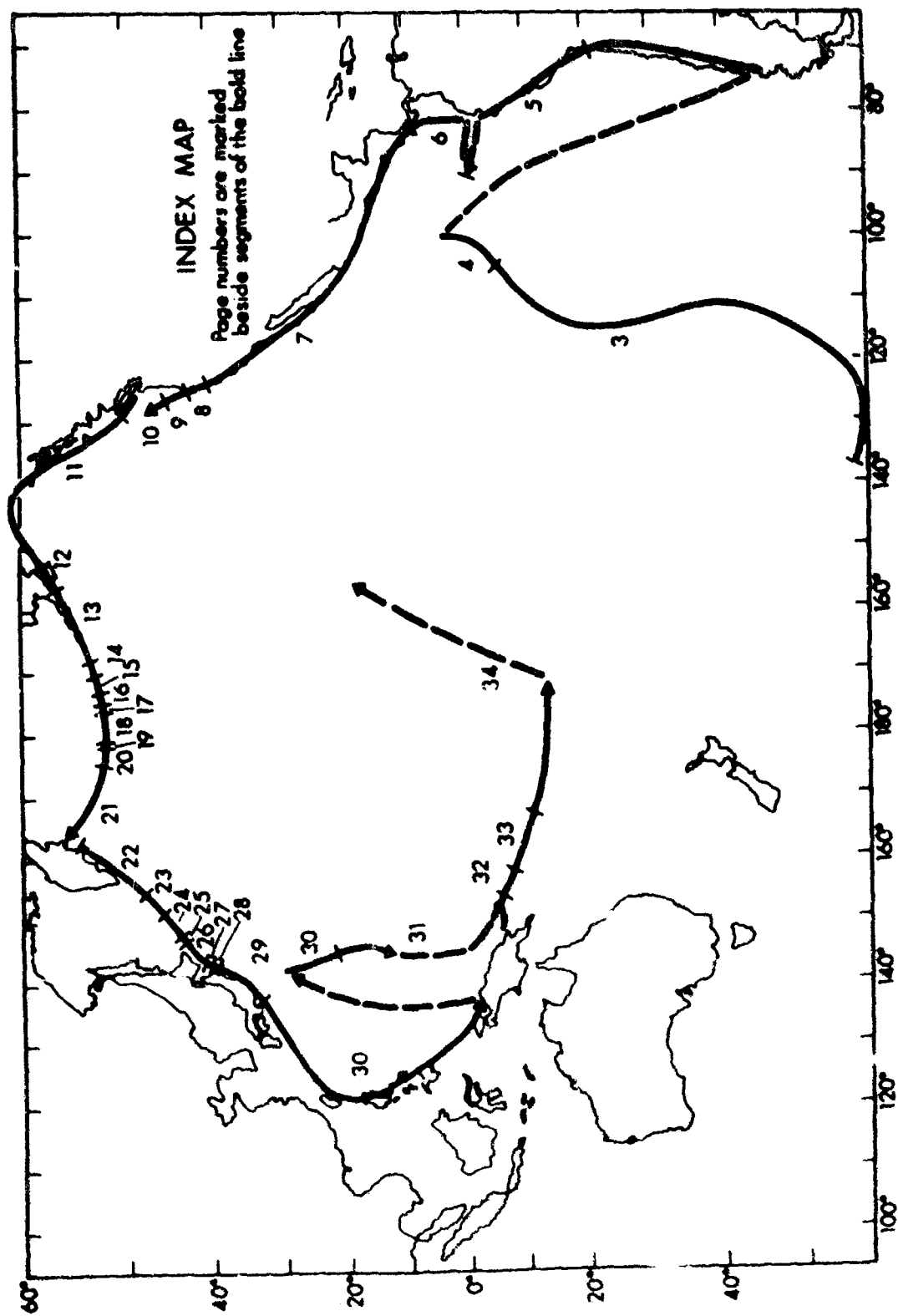
APPENDIX

The order of the sonagrams presented here is by geographic location starting on the East Pacific Rise and proceeding as diagrammed on the map on the facing page. Page numbers are written by segments of the position line.

The annotation of sonagrams, with few exceptions, is the annotation used on C&GS Preliminary Determination of Epicenters cards. Some events which were not located by C&GS but by hydrophone network are marked by a dagger and annotated in the form used in the HIG T-Phase Source Locations.

C&GS annotation:

29 DEC 66	22 16 22.7	32.8S		111.7N
EASTER ISLAND CORDILLERA		33R	5.4	24
area name	Greenwich time	depth, km	magni-tude	hydro-phone no.

HIG T-Phase annotation:

†24 MAY 67	04 12 31	55.7S		136.6W
EAST PACIFIC RIDGE		7-4	44	23
area name	Greenwich time	number of phones-no. of stations	T-phase strength, db	hydro-phone no.

Hydrophones at Oahu, Midway, Wake, and Eniwetok are numbered in the 10's, 20's, 30's, and 40's, respectively.

The sonagrams display relative intensity contoured in the frequency-time plane. They have an intensity range of 42 db (seven 6 db contours). Frequencies range, vertically, from 0 to 50 hz. The duration of a single sonagram is 6.4 minutes.

A-1

09 SEP 67 16 52 013 543S 136.0W
SOUTH PACIFIC CORDILLERA 33R 5.4 23

27 DEC 67 00 27 29* 541S 132.2W
SOUTH PACIFIC CORDILLERA 33R 4.9 23

20 NOV 66 16 47 33* 551S 129.4W
SOUTH PACIFIC CORDILLERA 33R 4.9 22

10 MAY 67 14 07 44 561S 126.3W
EAST PACIFIC RIDGE 10-4 46 24

10 DEC 66 21 09 46 567S 123.8W
EAST PACIFIC RIDGE 10-4 48 25

31 AUG 66 23 36 06* 495S 116.5W
EASTER ISLAND CORDILLERA 33R 51 22

09 DEC 64 11 22 22* 35.1S 109.7W
EASTER ISLAND CORDILLERA 33 4.7 44

18 NOV 66 09 12 09.9 363S 100.7W
SOUTHERN PACIFIC OCEAN 33R 51 24

01 NOV 67 19 38 16* 34.1S 112.4W
EASTER ISLAND CORDILLERA 33R 4.7 25

29 DEC 66 22 16 227 32.6S 111.7N
EASTER ISLAND CORDILLERA 33R 5.4 24

22 JAN 68 17 36 51* 28.5S 112.8W
EASTER ISLAND REGION 33R 4.6 24

29 JAN 68 09 18 31*
EASTER ISLAND CORDILLERA

17 JUN 67 00 56 29.4 41.5S 104.7W
NORTH EASTER ISLAND CORDILLERA 33R 4.8 22

A-3

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08 NOV 67   10 47 45.3   20.0S   70.3W
NORTH CHILE   66   4.6   32

17 JUN 68   19 23 35.8   0.7S
GALAPAGOS ISLANDS   33R   4.6

08 JAN 68   19 44 24.5   18.6S   69.9W
NORTH CHILE   16   5.4   43

17 JUN 68   21 16 45.2   0.7S   91.7W
GALAPAGOS ISLANDS   33R   4.6   23

21 DEC 67   07 50 34.8   16.4S   72.6W
PERU   99   5.0   32

16 JUN 68   12 59 57.6   0.3S   91.7W
GALAPAGOS ISLANDS   33R   4.7   23

17 OCT 66   21 41 56.3   10.7S   78.7W
PERU   38   7+   16
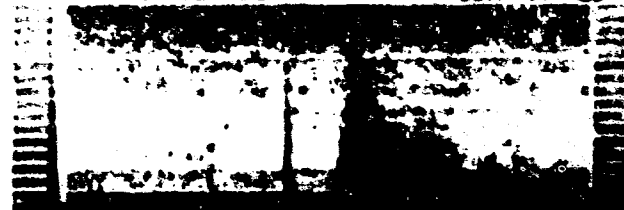
19 JUN 68   16 47 41.7   0.1S   91.7W
GALAPAGOS ISLANDS   33R   4.7   16

24 SEP 63   16 30 16.0   10.6S   78.0W
PERU   80   6.5   15
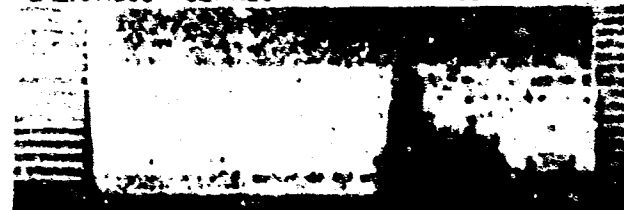
19 JUN 68   12 36 45.7   0.5S   91.6W
GALAPAGOS ISLANDS   33R   4.6   16

20 APR 67   14 07 23.3   8.3S   80.1W
OFF COAST OF NORTH PERU   78   4.6   24

18 JUN 68   23 21 51.2   0.5S   91.5W
GALAPAGOS ISLANDS   33R   4.4   24

19 JUN 68   13 44 31   0.9S   91.9W
GALAPAGOS ISLANDS   33R   4.6   16
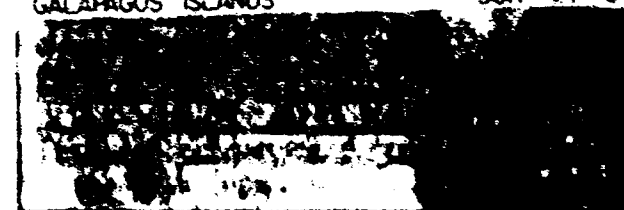
17 JUN 68   08 09 00.7   0.6S   91.5W
GALAPAGOS ISLANDS   33R   4.8   23

Left column:
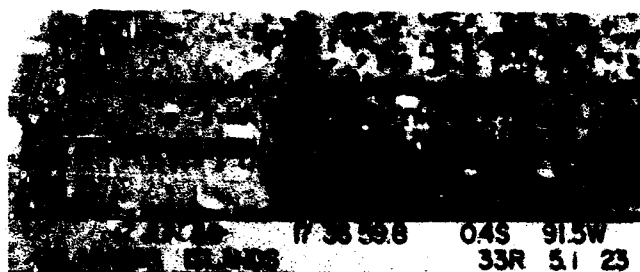
17 36 59.8   0.4S 91.5W
...ISLANDS   33R 5.1 23

17 JUN 68   04 18 22.0   0.2S 91.5W
GALAPAGOS ISLANDS   33R 4.5 23

16 JUN 68   08 58 10.3   0.2S 91.5W
GALAPAGOS ISLANDS   33R 4.7 23

17 JUN 68   14 54 40.7   0.3S 91.2W
GALAPAGOS ISLANDS   33R 4.5 23
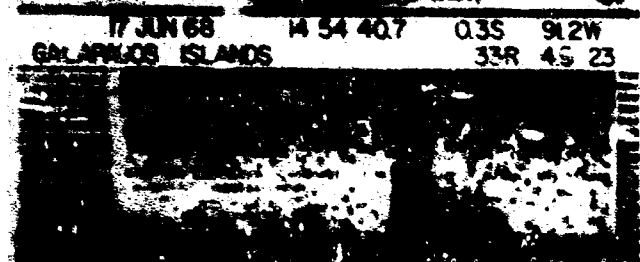
JUN 68   16 17 05   0.3S 91.2W
GALAPAGOS ISLANDS   33R 4.8 15

16 JUN 68   07 13 16.7   0.2S 91.2W
GALAPAGOS ISLANDS   33R 4.9 16

17 JUN 68   8 30 29   0.3S 91 W
GALAPAGOS ISLANDS   33R 4.6 23

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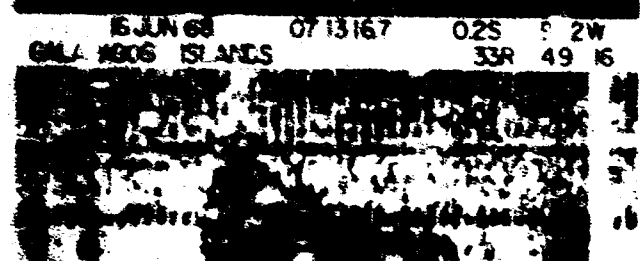
19 JUN 68   15 05 47   0.0S 91.1W
GALAPAGOS ISLANDS   33R 5.1 16
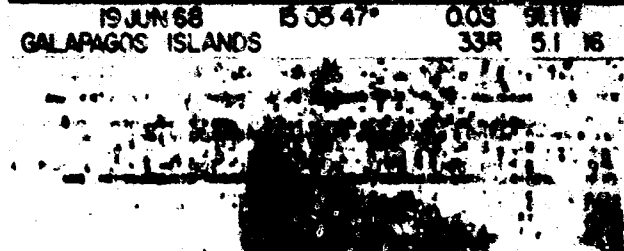
17 JUN 68   08 51 13.7   0.1N 91.3W
GALAPAGOS ISLANDS   33R 5.0 23

15 MAY 68   02 29 30.1   1.4N 90.6W
GALAPAGOS ISLANDS   33R 4.5 43
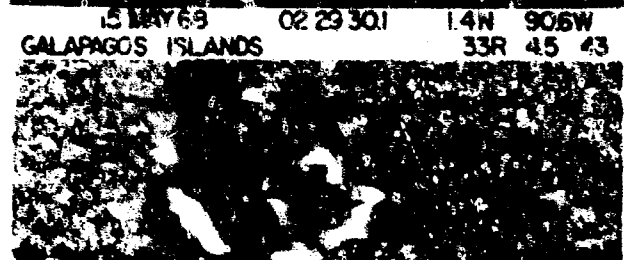
29 JUN 67   04 32 30.1   5.2N 82.7W
SOUTH OF PANAMA   33R 4.8 24
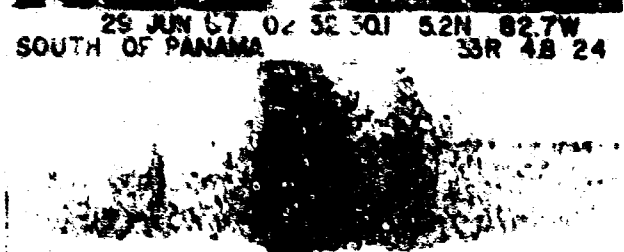
11 JAN 67   16 02 04.1   5.3N 82.5W
PANAMA   22 5.3 44
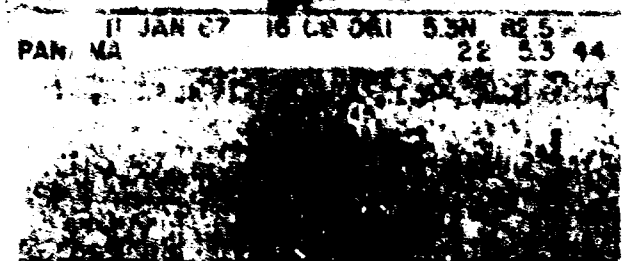
03 JAN 68   06 58 56.7   5.3N 82.5W
SOUTH OF PANAMA   27 4.6 15
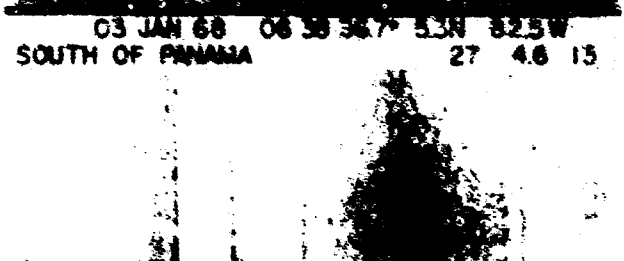
23 APR 67   22 25 27.4   6.1N 83.3W
COSTA RICA   46 4.5 24

13 NOV 67   16 05 465   10.4N   85.7W
COSTA RICA   18   4.6   42

06 FEB 68   22 47 52.4   10.2N   103.7W
OFF MEXICO   53   4.8   24

20 JAN 68   21 41 09.8   16.1N   105.4W
MEXICO   51   4.8   16

03 JAN 68   19 14 56°   10.9N   102.7W
OFF MEXICO   33R   4.6   13

30 JUN 68   20 04 341   17.9N   105.5W
MEXICO   33R   4.5   22

30 JUN 68   20 21 277   17.9N   105.8W
MEXICO   35   4.8   22

30 JUN 68   21 08 35°   18.0   105.5W
MEXICO   33R   4.0   22

04 APR 67   18 20 05   18
MEXICO

24 SEP 66   08 57 10.2   12.0N   130.0W
CENTRAL PACIFIC OCEAN   33   5.3   43

30 AUG 66   23 37 19°   18.7N   107.0N
REVILLA GIGEDO   54   5.3   43

17 FEB 68   21 00 33°   20.2N   108.1W
REVILLA GIGEDO   33R   4.1   16

23 APR 68   13 18 33.0   31.7N   114.9W
BAJA CALIFORNIA   33R   4.7   16

18 DEC 67   17 24 31.9   37.0N   121.8W
CENTRAL CALIFORNIA COAST   11   5.0   23

27 JUN 68   11 22 45°   40.0N   124.3W
NORTH CALIFORNIA   33R   4.2   13

A-7

04 19 20°   40.1N 124.5W
CALIFORNIA   33R 4.2 24

26 JUN 68   02 53 42°   40.1N 124.4W
NORTH CALIFORNIA   33R 4.1 34

02 23 09°   40.2N 124.7W
CALIFORNIA   33R 4.5 24

26 JUN 68   05 50 29.6   40.2N 124.6W
NORTH CALIFORNIA   33R 4.3 24

26 JUN 68   10 47 46.0   40.2N 124.4W
NORTH CALIFORNIA   33R 5.1 32

26 NOV 66   04 30 58°   40.3N 125.5W
OFF CALIFORNIA   33R 4.5 15

26 NOV 66   05 56 39°   40.3N 125.3W
OFF CALIFORNIA   33R 4.6 15

26 JUN 68   09 10 14.3   40.3N 124.6W
NORTH CALIFORNIA   33R 4.5 32

24 NOV 67   13 57 00.4   40.4N 125.1W
MENDOCINO ESCARPMENT (CALIFORNIA) 17 4.6 13

10 DEC 67   12 06 50.3   40.5N 124.6W
OFF NORTH CALIFORNIA   5   58 23

10 DEC 67   12 33 54.2   40.5N 125.0W
OFF NORTH CALIFORNIA   15   4.6 23

22 AUG 63   09 27 09.3   42.0N 126.2W
OFF OREGON   53   5.6 22

26 SEP 67   05 51 11°   42.0N 126.2W
OFF OREGON   33R 4.9 13

26 JUN 68   04 35 24°   42.2N 125.9W
OFF OREGON   33R 4.1 24

A-8

19 NOV 66   15 47 27°   42.2N 125.8W
OFF OREGON   33R 4.5 22

08 MAY 68   12 17 13.4   43.6N
OFF OREGON

13 DEC 67   13 23 17°   42.6N 126.0W
OFF OREGON   33 4.4 24

19 FEB 68   18 03 10.4   43.6N 127.4W
OFF OREGON   33R 4.8 13

13 DEC 67   10 12 44°   43.2N 125.9W
OFF OREGON   33R 4.3 24

07 FEB 68   08 35 29.6   43.8N 126.6W
OFF OREGON   33R 5.1 24

31 AUG 65   11 26 23°   43.3N 126.0W
OFF OREGON   33 4.2 16

09 JAN 68   11 44 52°   43.7N 127.6W
OFF OREGON   33R 4.4 30

09 MAY 68   03 03 01.8   43.4N 127.0W
OFF OREGON   33R 5.2 43

04 DEC 67   08 48 45.2   43.7N 127.4W
OFF OREGON   33R 4.6 25

13 NOV 67   17 44 13°   43.4N 126.8W
OFF OREGON   33 4.2 16

08 MAY 68   21 53 02.9   43.9N 128.2W
OFF OREGON   33R 4.6 44

19 JAN 68   20 23 37.9   43.4N 126.6W
OFF OREGON   33 4.6 13

28 DEC 67   07 01 36.8   44.2N 129.0W
OFF OREGON   33R 4.9 24

44.2N 12...W
33R 5.0 2?

44.2N 12?.?W
33R 5.4 24

44.?N 12?.?W
33R 4.0 24

...C 67   09 15 37.1   44.5N   128.9W
...GON   33R 4.3 23

...DEC 6?   07 36 49.8   44.4N   128.8W
OFF OREGON   33R 4.4 13

2? DEC 67   09 49 50.8   44.5N   129.8W
OFF OREGON   33R 4.5 24

26 DEC 67   09 29 38.5   44.5N   129.7W
OFF OREGON   33R 5.1 24

25 DEC 67   10 4? 22°   44.?N   ?.?W
OFF OREGON   33R 4.? 13

26 DEC 67   10 27 58°   44.7N   128.7W
OFF OREGON   33R 4.4 24

26 DEC 67   10 38 5?°   44.7N   128.?W
OFF OREGON   33R 3.7 24

03 JAN 67   20 13 31.8   45.7N   126.5W
OFF OREGON   33 4.7 16

16 FEB 67   06 40 54   48.6N   131.0W
WEST OF VANCOUVER   8-4 32 22

02 MAR 68   03 14 44.5   49.2N   129.1W
WEST OF VANCOUVER   33R 5.1 13

02 JUL 65   22 55 57°   49.3N   129.8W
WEST OF VANCOUVER   33 3.9 15

09 SEP 67   14 45 42*   49.8N 129.1W
WEST OF VANCOUVER   33R 4.0 13

30 MAR 64   04 22 43.1   58.0N 146.6W
GULF OF ALASKA   15   4.6 13

1 23 MAR 67   11 57 51   50.0N 130.4W
QUEEN CHARLOTTE IS   11-4 8   16

30 MAR 64   01 32 09.5   59.8N 146.6W
GULF OF ALASKA   15   4.6 13

01 FEB 68   07 58 03.5   50.0N 129.8W
WEST OF VANCOUVER   14   5.4 16

21 JUN 68   15 09 38.9   58.4N 149.8W
GULF OF ALASKA   33R 4.0 25

16 FEB 67   02 58 32   50.6N 130.6W
QUEEN CHARLOTTE IS   2   14-5 33

12 FEB 68   26 14 55.6   57.3N 149.8W
GULF OF ALASKA   33R 4.2 24

01 SEP 66   14 11 25*   50.6N 129.5W
WEST OF VANCOUVER   33   4.6 34

07 NOV 67   22 09 00.0   57.3N 150.0W
GULF OF ALASKA   33R 4.2 22

28 APR 67   00 00 41.8   51.2N 130.4W
QUEEN CHARLOTTE IS   6   5.1 24

04 APR 68   06 07 54.5   56.3N 150.1W
GULF OF ALASKA   30   3.9 24

30 MAR 64   07 09 34.0   59.9N 145.7W
GULF OF ALASKA   15   5.6 13

30 MAR 64   02 02 35*   56.7N 151.6W
KODIAK ISLAND REGION   33   4.2 13

30 MAR 64   05 32 30°   56.9N   151.7W
KODIAK ISLAND REGION   33   4.3   13

24 MAY 67   03 59 14°   56.7N   152.1W
KODIAK ISLAND REGION   14   4.0   16

24 MAY 67   08 18 55.4   55.4N   152.6W
KODIAK ISLAND REGION   33   5.3   23

30 MAR 64   04 01 36°   56.4N   152.8W
KODIAK ISLAND REGION   33   4.3   13

30 MAR 64   02 18 063   56.6N   152.9W
KODIAK ISLAND REGION   25   5.8   13
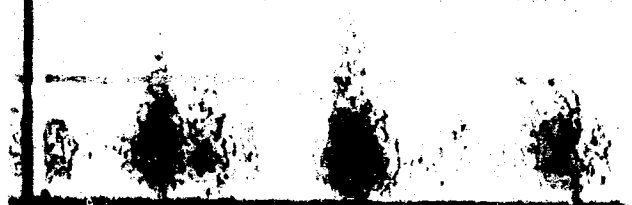
30 MAR 64   02 41 59.6   56.5N   153.0W
KODIAK ISLAND REGION   30   4.9   13

30 MAR 64   08 40 10.7   56.5N   153.0W
KODIAK ISLAND REGION   20   4.3   13

30 MAR 64   08 53 17.9   56.2N   153.1W
KODIAK ISLAND REGION   30   4.3   13

29 MAR 64   23 08 28.6   56.1N   153.5W
KODIAK ISLAND REGION   15   4.6   23

30 MAR 64   03 12 17.1   56.0N   153.6W
KODIAK ISLAND REGION   33   4.1   13

10 APR 67   19 57 34.4   58.6N   154.3W
ALASKA PENINSULA   86   5.5   13

06 FEB 64   15 00 32.6   56.1N   154.3W
KODIAK ISLAND REGION   33   4.4   24

04 APR 67   09 00 08.3   55.5N   155.1W
SOUTH OF ALASKA   27   4.5   24

06 FEB 64   13 07 25.2   55.8N   155.8W
SOUTH OF ALASKA   33   5.6   32
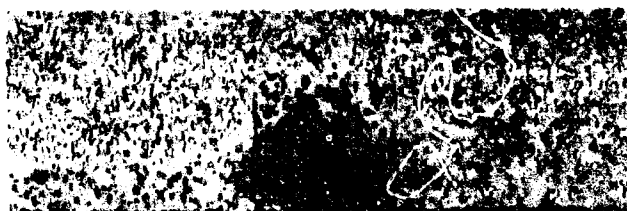
07 FEB 67 14 53 13.9 56.7N 157.2W
ALASKA PENINSULA 67R 5.6 16

29 APR 66 01 46 43° 53.8N 157.8W
SOUTH OF ALASKA 33 5.2 15

01 JUL 67 23 10 07.2 54.4N 158.0W
SOUTH OF ALASKA 33R 6.2 13

02 JUL 67 01 09 38.1 54.5N 158.1W
SOUTH OF ALASKA 33R 4.2 24

06 FEB 64 15 57 17° 55.4N 160.8W
ALASKA PENINSULA 33 4.1 24

01 JUL 67 21 22 10.0 54.0N 161.0W
ALASKA PENINSULA 19 4.5 13

18 NOV 65 22 08 45.7 53.1N 161.8W
SOUTH OF ALASKA 8 5.3 44
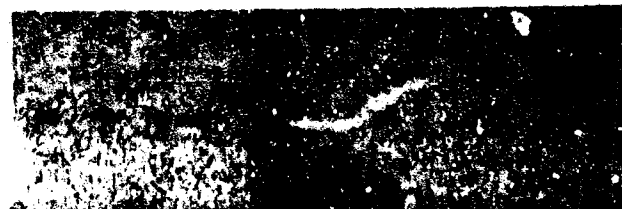
16 SEP 66 17 10 39.0 53.8N
UNIMAK ISLAND REGION 34

09 DEC 67 22 11 12.9 53.8N 163.2W
UNIMAK ISLAND REGION 14 4.3 42

01 JUN 67 03 36 51 53.1N 166.6W
FOX ISLANDS, ALEUTIAN ISLANDS 60 5.7 29

19 OCT 67 01 22 20° 52.7N 166.5W
FOX ISLANDS, ALEUTIAN ISLANDS 33R 4.3 22
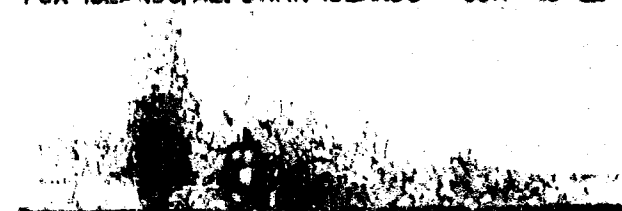
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FOX ISLANDS, ALEUTIAN ISLANDS 33R 5.7 13
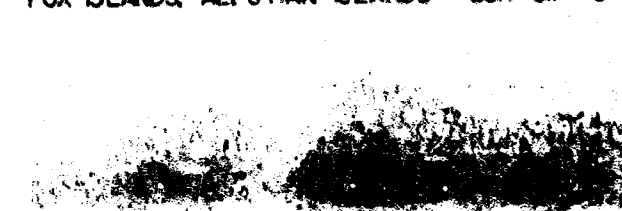
02 SEP 66 21 13 19° 53.7N 167.5W
FOX ISLANDS, ALEUTIAN ISLANDS 33 4.6 32

09 SEP 67 03 15 13° 53.4N 167.5W
FOX ISLANDS, ALEUTIAN ISLANDS 33R 4.1 22

02 JUL 66   20 58 40.3   53.1N 167.6W
FOX ISLANDS, ALEUTIAN ISLANDS   60 6.7 28

28 JAN 67   15 34 21°   52.5N 169.4W
FOX ISLANDS, ALEUTIAN ISLANDS   33 4.6 16

27 DEC 67   05 34 52°   52.9N 168.0W
FOX ISLANDS, ALEUTIAN ISLANDS   33R 4.5 24

28 JAN 67   20 48 34.0   52.5N 169.4W
FOX ISLANDS ALEUTIAN ISLANDS   47 4.4 16
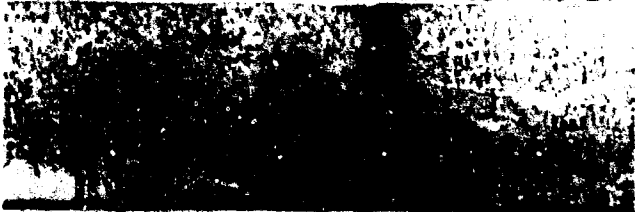
18 JAN 67   08 18 22.0   52.5N 168.3W
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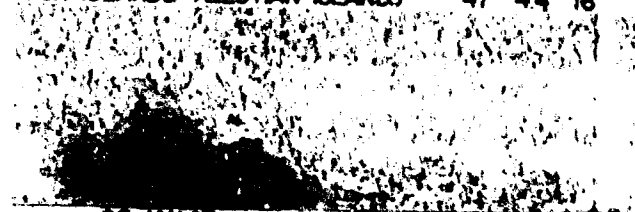
28 JAN 67   17 42 01.5   52.4N 169.4W
FOX ISLANDS, ALEUTIAN ISLANDS   50R 5.6 16

18 JAN 67   09 05 59°   52.4N 168.3W
FOX ISLANDS, ALEUTIAN ISLANDS   33 3.8 13

28 JAN 67   18 53 31°   52.4N 169.4W
FOX ISLANDS, ALEUTIAN ISLANDS   54 4.2 16

30 MAY 67   10 00 23   51.8N 168.6W
FOX ISLANDS, ALEUTIAN ISLANDS   33 4.2 16

28 JAN 67   17 26 32.8   52.3N 169.4W
FOX ISLANDS, ALEUTIAN ISLANDS   33 4.3 16

28 JAN 67   16 00 09°   52.9N 169.3W
FOX ISLANDS, ALEUTIAN ISLANDS   33 3.5 16

28 JAN 67   20 10 21°   52.0N 169.4W
FOX ISLANDS, ALEUTIAN ISLANDS   33 4.2 16

28 JAN 67   16 31 21.1   52.5N 169.3W
FOX ISLANDS, ALEUTIAN ISLANDS   32 5.6 16
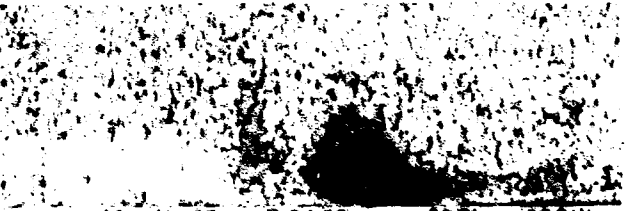
28 JAN 67   17 04 58   52.7N 169.9W
FOX ISLANDS, ALEUTIAN ISLANDS   11-5 12 16

28 JAN 67   21 02 55°   52.5N   169.5W
FOX ISLANDS, ALEUTIAN ISLANDS   33 3.8 16

29 JUL 65   11 13 38°   51.4N 171.?
FOX ISLANDS, ALEUTIAN ISLANDS   33 4.0

25 JAN 68   11 22 22.0   51.5N 169.6W
FOX ISLANDS, ALEUTIAN ISLANDS   15 4.7 16

29 JUL 65   09 32 00.8   51.1N 171.7W
FOX ISLANDS, ALEUTIAN ISLANDS   33 4.5 44

28 JAN 67   15 45 22°   52.2N 169.6W
FOX ISLANDS, ALEUTIAN ISLANDS   33 4.0 16
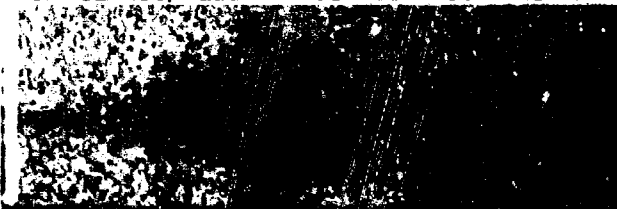
22 SEP 65   07 27 33.8   50.6N 172.8W
ANDREANOF ISLANDS, ALEUTIAN IS   36 4.6 15

04 JAN 68   00 57 44.4   52.2N 171.3W
FOX ISLANDS, ALEUTIAN ISLANDS   36 5.7 23

13 MAY 67   03 16 56   52.2N 173.4W
ANDREANOF ISLANDS, ALEUTIAN IS   13-5 23 13

07 AUG 66   02 13 05.1   50.6N 171.3W
FOX ISLANDS, ALEUTIAN ISLANDS -   39 6.5 15

11 AUG 67   10 43 30   52.3N 171.4W
FOX ISLANDS, ALEUTIAN ISLANDS   38 4.3 23

13 MAY 67   03 20 12   52.2N 173.4W
ANDREANOF ISLANDS, ALEUTIAN IS   15-5 32 13

29 JUL 65   08 29 21.2   50.9N 171.4W
FOX ISLANDS, ALEUTIAN ISLANDS   22 6.3 15

03 03 44   52.1N 173.4W
ISLANDS, ALEUTIAN IS   12-4 14 13

09 DEC 67   23 53 53*   51.8N 173.5W
ANDREANOF ISLANDS, ALEUTIAN IS   33R 4.0 43
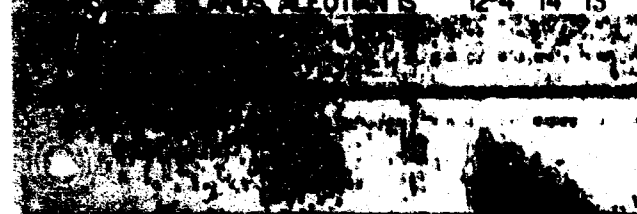
05 MAY 68   11 12 00.2   51.7N 173.4W
ANDREANOF ISLANDS, ALEUTIAN IS   32 4.1 23

1 13 MAY 67   06 14 44   50.0N 173.5W
ANDREANOF ISLANDS, ALEUTIAN IS   12-4 15 13
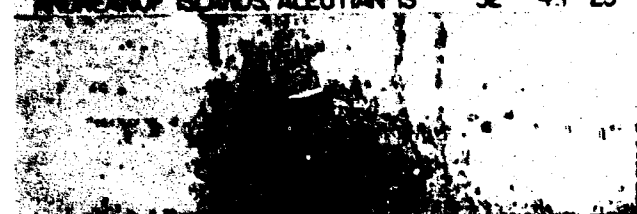
05 DEC 67   09 05 13.1   51.6N 173.4W
ANDREANOF ISLANDS, ALEUTIAN IS   36 5.3 30

13 MAY 67   06 18 1*   52.3N 173.6W
ANDREANOF ISLANDS, ALEUTIAN IS   33R 4.3 13
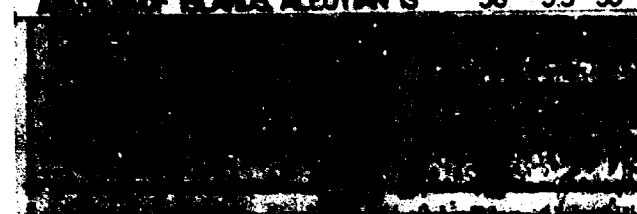
1 13 MAY 67   07 33 12   52.2N 173.5W
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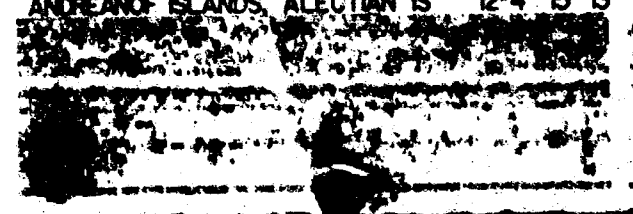
1 13 MAY 67   06 42 55   52.0N 173.6W
ANDREANOF ISLANDS, ALEUTIAN IS   12-4 30 13

1 13 MAY 67   07 14 06   51.9N 173.5W
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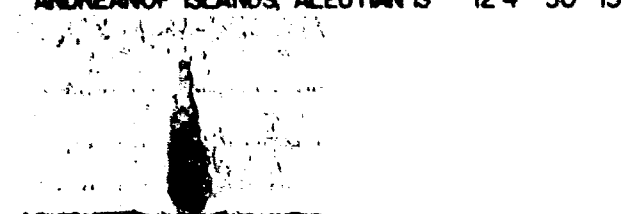
1 13 MAY 67   06 39 20   51.8N 173.6W
ANDREANOF ISLANDS, ALEUTIAN IS   12-4 34 13

1 13 MAY 67   07 16 26   51.9N 173.5W
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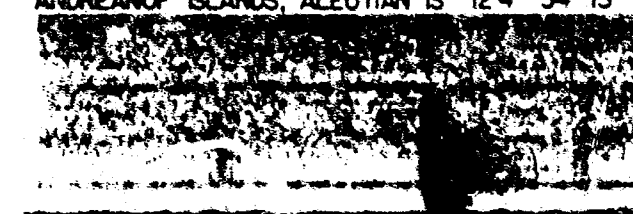
1 13 MAY 67   06 58 09   51.6N 173.6W
ANDREANOF ISLANDS, ALEUTIAN IS   12-4 34 13

1 13 MAY 67   07 04 05   51.8N 173.5W
ANDREANOF ISLANDS, ALEUTIAN IS   12-4 30 13

13 MAY 67   01 08 39*   52.2N 174.8W
ANDREANOF ISLANDS, ALEUTIAN IS   58 4.0 23

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21 FEB 68   06 18 21.6   52.3N 175.3W
ANDREANOF ISLANDS, ALEUTIAN IS   108   5.2 16

21 FEB 68   21 07 56.9   51.4N 176.9W
ANDREANOF ISLANDS, ALEUTIAN IS   47   5.2 24

22 FEB 68   12 53 33*   51.5N 175.6W
ANDREANOF ISLANDS, ALEUTIAN IS   20   4.3 24

22 FEB 68   16 49 58.6   51.4N 176.1W
ANDREANOF ISLANDS, ALEUTIAN IS   54   4.5 23

21 FEB 68   19 32 32.2   51.7N 175.9W
ANDREANOF ISLANDS, ALEUTIAN IS   54   4.8 23

21 FEB 68   19 08 39.3   51.4N 176.1W
ANDREANOF ISLANDS, ALEUTIAN IS   49   4.7 23

21 FEB 68   21 28 17*   51.7N 176.0W
ANDREANOF ISLANDS, ALEUTIAN IS   49   4.2 23

22 FEB 68   14 43 46*   51.6N 176.2W
ANDREANOF ISLANDS, ALEUTIAN IS   65   3.8 23

07 DEC 66   22 09 02*   51.7N 176.0W
ANDREANOF ISLANDS, ALEUTIAN IS   64   4.7 16

22 FEB 68   17 46 57.4   51.4N 176.2W
ANDREANOF ISLANDS, ALEUTIAN IS   49   5.1 23

21 FEB 68   19 30 04.9   51.6N 176.0W
ANDREANOF ISLANDS, ALEUTIAN IS   57   4.7 23

22 FEB 68   17 56 40*   51.4N 176.2W
ANDREANOF ISLANDS, ALEUTIAN IS   56   4.1 23

25 FEB 68   18 08 19.9   51.4N 176.0W
ANDREANOF ISLANDS, ALEUTIAN IS   50   5.3   3

22 FEB 68   13 13 59.3   51.4N 176.2W
ANDREANOF ISLANDS, ALEUTIAN IS   66   4.4 23

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23 FEB 66   00 10 38.5   51.5N   176.3W
ANDREANOF ISLANDS, ALEUTIAN IS   65   4.5   13

01 OCT 65   09 14 29ᵃ   51.5N   176.3W
ANDREANOF ISLANDS, ALEUTIAN IS   33   4.1   15

15 NOV 66   16 26 05   51.5N   176.5W
ANDREANOF ISLANDS, ALEUTIAN IS   61   4.5   23

29 APR 67   03 55 20.8   51.4N   178.3W
ANDREANOF ISLANDS, ALEUTIAN IS   50   6.0   44

30 MAY 67   09 54 38.3   50.1N   176.6W
ANDREANOF ISLANDS, ALEUTIAN IS   30R   5.0   23

07 SEP 66   05 28 44.2   51.2N   179.2W
ANDREANOF ISLANDS, ALEUTIAN IS   33   4.8   24

14 MAY 69   19 32 54.2   51.3N   179.9W
ANDREANOF ISLANDS, ALEUTIAN IS   21   6.2   42

29 JUN 67   04 53 25.0   51.7N   177.0W
ANDREANOF ISLANDS, ALEUTIAN IS   58   4.6   23

29 JAN 68   11 49 18.7   51.2N   179.1E
RAT ISLANDS, ALEUTIAN ISLANDS   45   4.6   13

28 JAN 66   19 07 15.0   51.7N   177.0W
ANDREANOF ISLANDS, ALEUTIAN IS   54   5.2   15

06 NOV 67   17 03 04.1   51.1N   178.7E
RAT ISLANDS, ALEUTIAN ISLANDS   42   5.3   13

23 FEB 66   01 40 12ᵃ   51.6N   177.2W
ANDREANOF ISLANDS, ALEUTIAN IS   54   4.5   13

06 NOV 67   17 09 27.1   51.1N   178.7E
RAT ISLANDS, ALEUTIAN ISLANDS   29   5.3   13

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08 NOV 67   17 22 32.1   51.1N 178.7E
RAT ISLANDS, ALEUTIAN ISLANDS   IC   5.3 13

30 MAR 65   09 03 12.7   50.2N 177.9E
RAT ISLANDS, ALEUTIAN ISLANDS   38   4.7 16

08 NOV 67   19 40 27.   51.1N 178.7E
RAT ISLANDS, ALEUTIAN ISLANDS   42   5.3 24

30 MAR 65   03 02 57.   50.4N 177.9E
RAT ISLANDS, ALEUTIAN ISLANDS   30   5.1 16
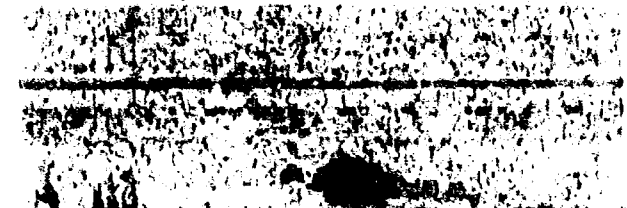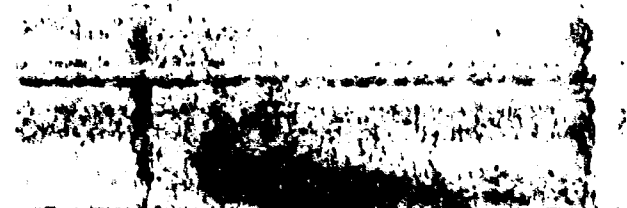
08 NOV 67   19 53 55.5   51.1N 178.4E
RAT ISLANDS, ALEUTIAN ISLANDS   32   4.6 24

30 MAR 65   02 27 07.2   50.6N 177.9E
RAT ISLANDS, ALEUTIAN ISLANDS   51   7   28

30 MAR 65   08 54 18.   50.1N 178.3E
RAT ISLANDS, ALEUTIAN ISLANDS   33   4.3 16

29 JUL 65   07 08 19.   51.4N 177.9E
RAT ISLANDS, ALEUTIAN ISLANDS   33   4.9 24
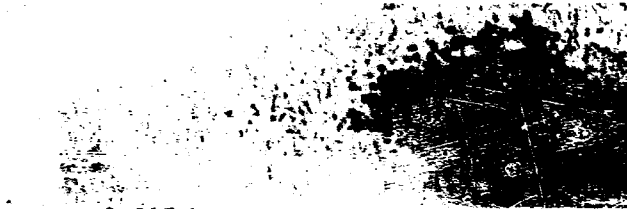
01 OCT 65   08 52 04.4   50.1N 178.2E
RAT ISLANDS, ALEUTIAN ISLANDS   23   6.3 24
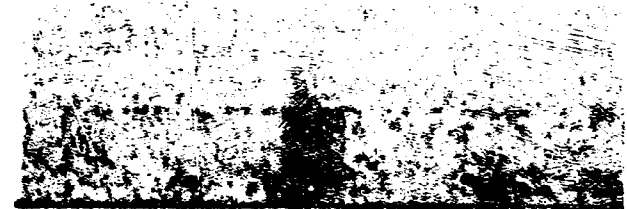
01 OCT 65   09 09 41.   50.1N 178.2E
RAT ISLANDS, ALEUTIAN ISLANDS   16   5.1 24

30 MAR 65   07 10 53.4   50.2N 177.8E
RAT ISLANDS, ALEUTIAN ISLANDS   35   4.9 16
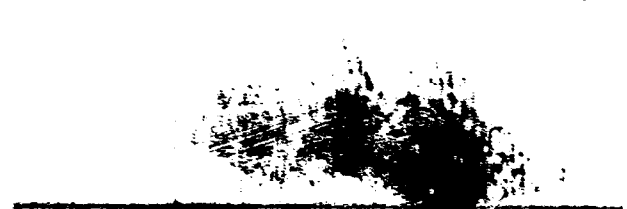
11 MAR 68   18 25 13.5   52.1N 178.2E
RAT ISLANDS, ALEUTIAN ISLANDS   121 5.2 32

30 MAR 65   07 21 06   50.2N 177.7E
RAT ISLANDS, ALEUTIAN ISLANDS   33   5.0 16
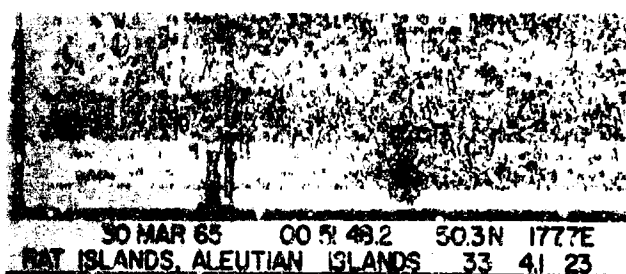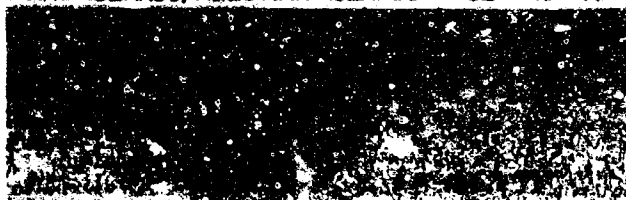
30 MAR 65   00 51 48.2   50.3N   177.7E
RAT ISLANDS, ALEUTIAN ISLANDS   33   41 23
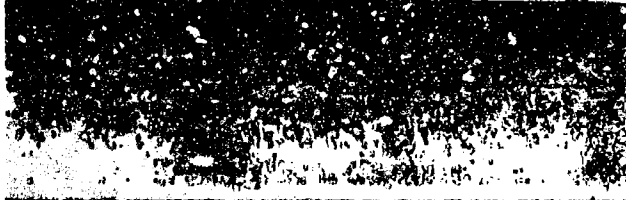
30 MAR 65   08 11 07.3   50.5N   177.5E
RAT ISLANDS, ALEUTIAN ISLANDS   35   4.7 16
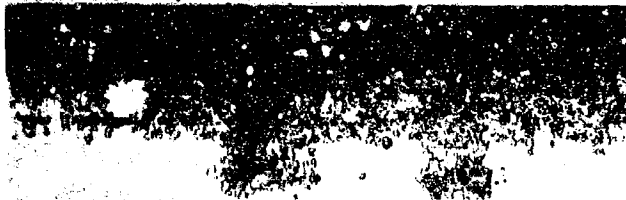
30 MAR 65   07 40 37.5   50.3N   177.4E
RAT ISLANDS, ALEUTIAN ISLANDS   32   4.7 16

30 MAR 65   06 25 01.1   50.1N   177.3E
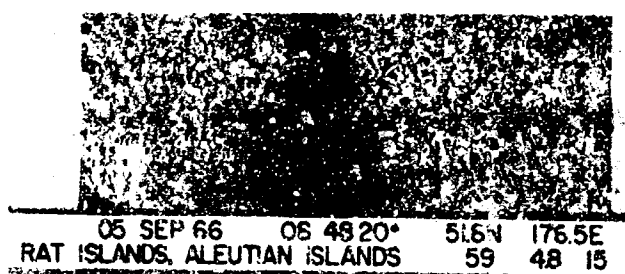RAT ISLANDS, ALEUTIAN ISLANDS   30   5.2 16

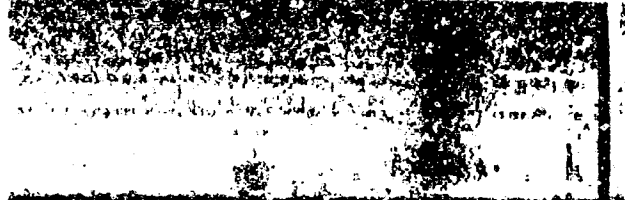13 AUG 65   20 51 06*   51.5N   177.0E
RAT ISLANDS, ALEUTIAN ISLANDS   33   4.1 22

26 DEC 67   14 41 27*   51.7N   176.9E
RAT ISLANDS, ALEUTIAN ISLANDS   33R   4.3 23

30 MAR 65   08 29 48*   51.7N   176.9E
RAT ISLANDS, ALEUTIAN ISLANDS   33   3.7 16

05 SEP 66   08 48 20*   51.6N   176.5E
RAT ISLANDS, ALEUTIAN ISLANDS   59   4.8 15

30 MAR 65   01 53 00.6   50.5N   176.0E
RAT ISLANDS, ALEUTIAN ISLANDS   33   4.8 16

29 MAY 67   03 41 05   51.7N   175.9E
RAT ISLANDS, ALEUTIAN ISLANDS   11-4   24 23

04 NOV 65   10 18 42*   52.0N   175.7E
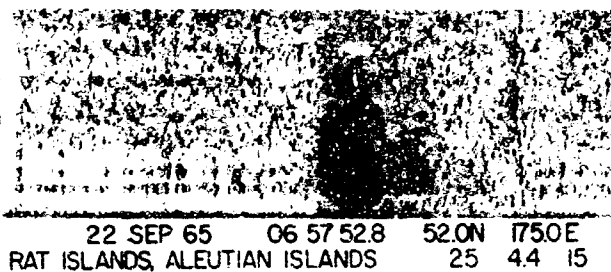RAT ISLANDS, ALEUTIAN ISLANDS   64   4.1 15
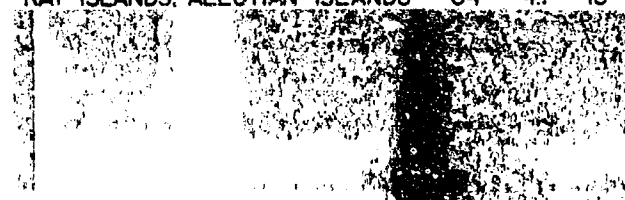
31 AUG 65   09 46 01*   51.5N   175.5E
RAT ISLANDS, ALEUTIAN ISLANDS   33   3.7 16

02 JUL 65   20 19 41.7   52.1N   175.4E
RAT ISLANDS, ALEUTIAN ISLANDS   37   5.4 15

06 AUG 66   21 04 32.5   51.9N   175.3E
RAT ISLANDS, ALEUTIAN ISLANDS   30   5.3 16

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22 SEP 65   06 57 52.8   52.0N 175.0E
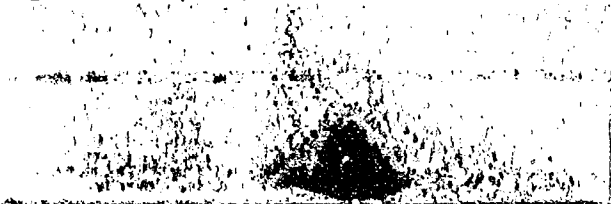RAT ISLANDS, ALEUTIAN ISLANDS   25   4.4   15

31 AUG 65   11 39 22*   52.3N 172.6E
NEAR ISLANDS, ALEUTIAN ISLANDS   33   5.1   14

17 AUG 66   20 58 35.9   52.3N 174.9E
NEAR ISLANDS, ALEUTIAN ISLANDS   32   5.6   22
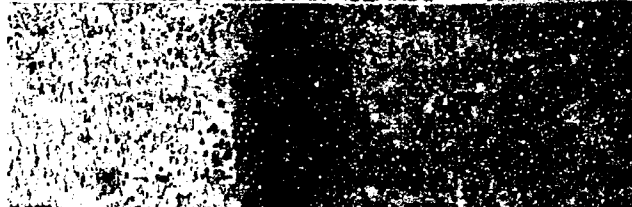
28 APR 68   04 18 15.7   44.8N 174.6E
NORTH PACIFIC OCEAN   39   5.5   23

26 FEB 68   10 39 06.2   51.1N 174.6E
NEAR ISLANDS, ALEUTIAN ISLANDS   33R   4.7   30

28 APR 68   06 23 02*   44.8N 174.7E
NORTH PACIFIC OCEAN   33R   4.3   23

23 MAR 67   08 45 20.2   52.3N 174.0E
NEAR ISLANDS, ALEUTIAN ISLANDS   62   4.4   16

16 OCT 65   20 01 52.9   56.1N 164.6E
KOMANDORSKY   41   5.4   30

07 MAY 67   11 03 49.5   51.8N 173.8E
NEAR ISLANDS, ALEUTIAN ISLANDS   18   4.6   24

23 JAN 67   21 45 33*   55.3N 163.0E
NEAR EAST COAST OF KAMCHATKA   33R   4.3   35

31 OCT 66   05 43 31*   52.1N 173.1E
NEAR ISLANDS, ALEUTIAN ISLANDS   33R   4.3   34

23 DEC 66   23 49 27*   54.8N 162.5E
NEAR EAST COAST OF KAMCHATKA   28   4.9   16

26 FEB 68   09 28 54.1   52.7N 172.6E
NEAR ISLANDS, ALEUTIAN ISLANDS   56   5.0   30
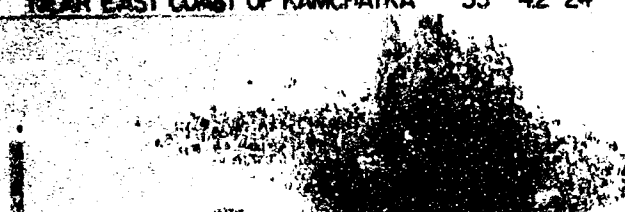
06 JUL 65   04 58 55.6   55.0N 162.0E
NEAR EAST COAST OF KAMCHATKA   34   5.2   22

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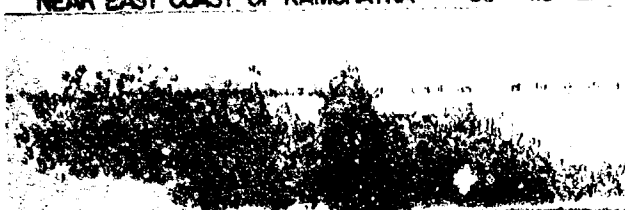23 56 09°   54.5N 162.2E
EAST COAST OF KAMCHATKA   33   4.6   16

06 DEC 66   07 18 40°   50.1N 159.8E
KURIL ISLANDS   27   5.4   24
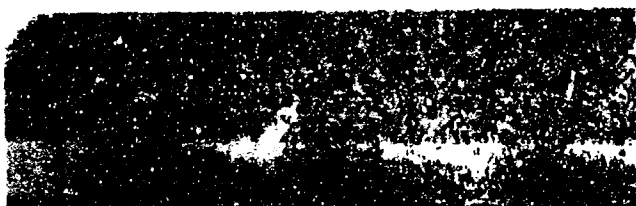
06 JUL 65   06 12 41°   54.3N 160.1E
NEAR EAST COAST OF KAMCHATKA   33   4.2   24

24 MAY 67   01 35 57°   50.0N 159.3E
KURIL ISLANDS   43   4.4   24

6 NOV 65   21 58 19.6   53.9N 160.6E
NEAR EAST COAST OF KAMCHATKA   67   6.1   44

13 DEC 67   10 58 21.6   49.4N 154.6E
KURIL ISLANDS   138   5.1   24

01 JUL 63   11 51 56°   53.8N 160.4E
NEAR EAST COAST OF KAMCHATKA   65   4.3   22

18 JAN 66   04 20 52.9   48.9N 154.9E
KURIL ISLANDS   40   5.4   13

28 JAN 67   22 28 01.2   55.0N 160.2E
KAMCHATKA   113   5.1   22

22 SEP 65   07 55 21°   48.7N 155.1E
KURIL ISLANDS   33   4.5   34
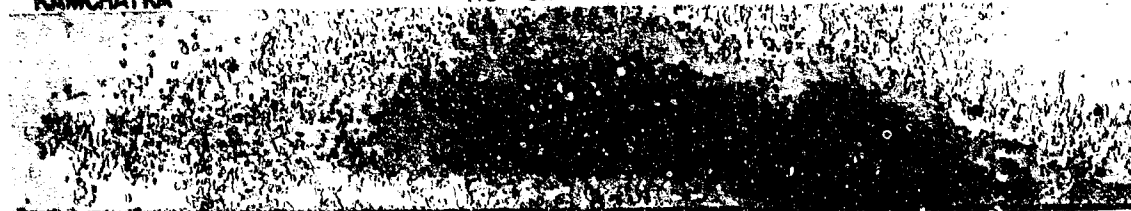
28 JAN 66   22 38 13.7   51.6N 157.0E
NEAR EAST COAST OF KAMCHATKA   112   5.7   22

12 MAR 67   01 23 49.5   51.1N 157.9E
NEAR EAST COAST OF KAMCHATKA   21   5.2   34

01 NOV 67   16 30 57.1   48.3N 154.4E
KURIL ISLANDS   40   5.5   44

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01 NOV 67   16 09 16.7   48.2N 154.4E
KURIL ISLANDS   47 5.3 44

14 AUG 65   01 27 18.0   47.3N 155.1E
KURIL ISLANDS   41 4.4 24

02 MAY 68   02 55 41*   48.2N 154.0E
KURIL ISLANDS   48 4.3 34

22 APR 67   23 00 32   46.8N 151.6E
KURIL ISLANDS   73 4.4 16

26 SEP 67   06 47 11.6   48.9N 150.6E
KURIL ISLANDS   136 4.7 22

26 SEP 67   06 47 11.6   46.9N 150.6E
KURIL ISLANDS   136 47 13

07 DEC 66   17 17 42.0   44.3N 151.7E
KURIL ISLANDS   26 5.8 32

06 FEB 64   09 40 16*   47.8N 152.4E
KURIL ISLANDS   65 4.3 32

16 MAY 67   05 08 31.6   45.5N 149.8E
KURIL ISLANDS   52R 4.7 16

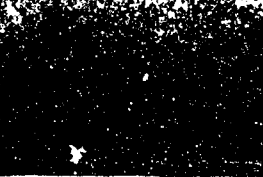06 JUL 65   04 08 47.4   46.8N 152.5E
KURIL ISLANDS   39 5.6 22

10 NOV 67   20 48 25.7   45.3N 149.8E
KURIL ISLANDS   95R 4.8 44

13 DEC 67   10 38 23.4   47.6N 152.6E
KURIL ISLANDS   124 5.5 24

20 OCT 63   00 53 07.2   44.7N 150.7E
KURIL ISLANDS   25 7.0 32

13 OCT 63   12 52 25.3   44.6N   150.5E
KURIL ISLANDS   30   4.6   24

13 OCT 63   08 34 40*   44.5N   150.9E
KURIL ISLANDS   33   4.5   24

20 OCT 63   02 09 29.4   44.7N   150.0E
KURIL ISLANDS   45   4.9   23

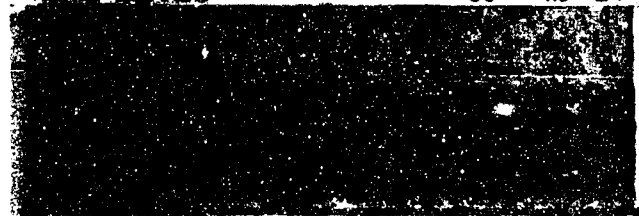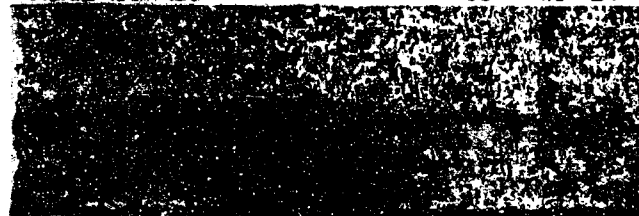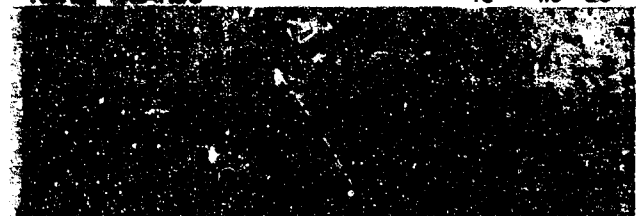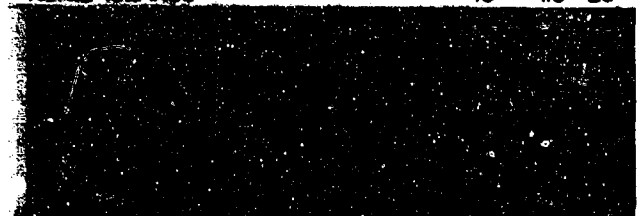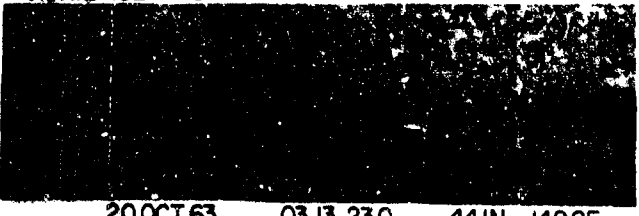20 OCT 63   01 14 05.2   44.6N   150.1E
KURIL ISLANDS   45   4.8   23

20 OCT 63   04 58 55.0   44.5N   149.7E
KURIL ISLANDS   50   4.4   23

19 OCT 63   00 42 41.9   44.3N   149.7E
KURIL ISLANDS   40   4.0   23

20 OCT 63   03 13 23.0   44.1N   149.8E
KURIL ISLANDS   40   4.3   23

13 OCT 63   01 26 34.3   44.4N   149.3E
KURIL ISLANDS   33   4.4   24
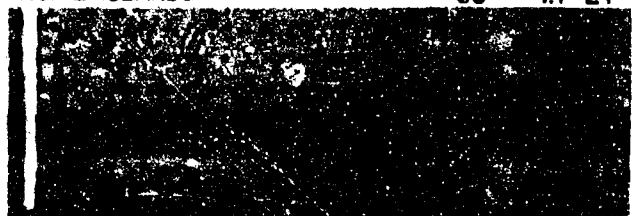
13 OCT 63   01 34 54.3   44.4N   149.2E
KURIL ISLANDS   33   4.4   24

13 OCT 63   04 05 50.1   44.4N   149.2E
KURIL ISLANDS   30   4.4   24

20 OCT 63   03 41 41.9   44.3N   149.4E
KURIL ISLANDS   45   3.9   23

12 OCT 63   23 40 11.1   44.3N   149.2E
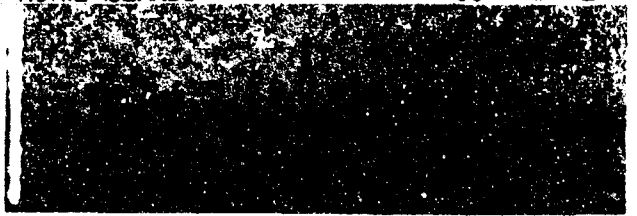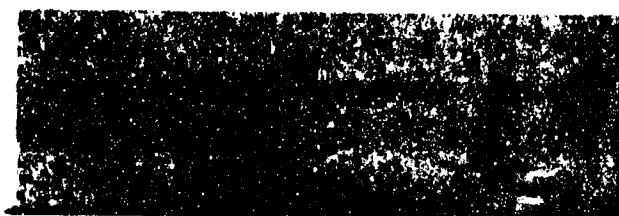KURIL ISLANDS   40   4.3   24

20 OCT 63   01 40 39.5   43.9N   149.8E
KURIL ISLANDS   40   4.2   23

06 JUL 65   06 39 25.0   44.5N   148.3E
KURIL ISLANDS   56   4.4   24

30 JAN 68   03 23 41.9   43.3N 147.4E
KURIL ISLANDS   33R 4.9 23

29 JAN 68   16 42 50.4   43.5N 147.2E
KURIL ISLANDS   36R 5.7 24

04 FEB 68   11 06 21.0   43.1N 147.0E
KURIL ISLANDS   35R 5.3 30

04 FEB 68   09 10 25.3   43.2N 147.2E
KURIL ISLANDS   33R 5.4 30
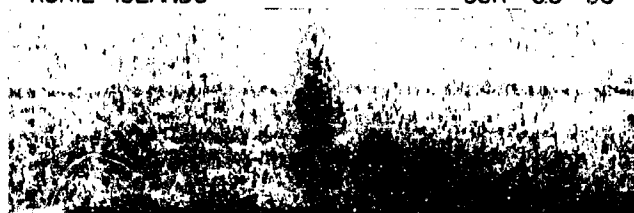
04 FEB 68   11 00 50.1   43.0N 147.1E
KURIL ISLANDS   33R 5.5 30

30 JAN 68   04 10 36.1   43.1N 147.1E
KURIL ISLANDS   24 5.1 24

21 APR 67   04 15 51*   43.3N 146.3E
KURIL ISLANDS   48 4.4 32

10 MAY 68   10 19 32*   43.6N 145.8E
HOKKAIDO, JAPAN REGION   60R 4.3 43

30 JAN 68   06 08 35.2   43.5N 147.1E
KURIL ISLANDS   33R 5.0 24

29 MAY 67   21 01 44.3   43.3N 145.7E
HOKKAIDO, JAPAN REGION   88R 5.3 34

12 MAR 67   02 51 54.7   42.6N 143.0E
HOKKAIDO, JAPAN REGION   33 5.3 23

29 JAN 68   10 19 05.6   43.6N 146.7E
KURIL ISLANDS   40 7.0 13

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24 JAN 67   03 05 39.0   41.4N   141.9E
HOKKAIDO, JAPAN REGION   69R   5.7   35
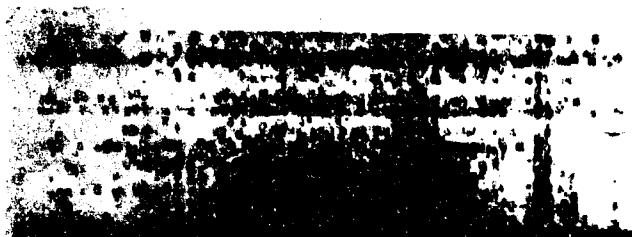
23 FEB 68   13 38 46.4   42.0N   142.4E
HOKKAIDO, JAPAN REGION   72   4.7   23

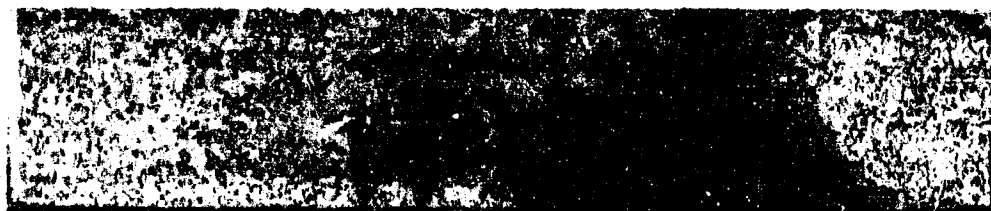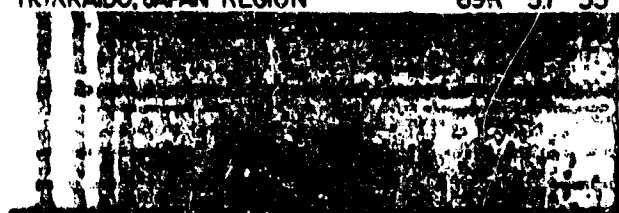26 JUN 68   05 54 24°   41.2N   142.9E
HOKKAIDO, JAPAN REGION   33R   4.3   35

05 DEC 66   10 45 02.0   41.9N   141.1E
HOKKAIDO, JAPAN REGION   127   4.3   32

21 JUN 68   13 49 32.6   41.2N   142.4E
HOKKAIDO, JAPAN REGION   33   4.1   23

23 JUN 68   04 57 52.2   41.6N   143.4E
HOKKAIDO, JAPAN REGION   45   4.2   24

17 JUN 68   11 53 00.4   41.0N   143.0E
HOKKAIDO, JAPAN REGION   48   5.7   23
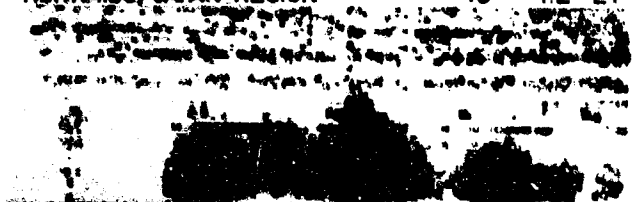
18 JUN 68   07 38 13°   41.5N   142.9E
HOKKAIDO, JAPAN REGION   33R   4.2   23
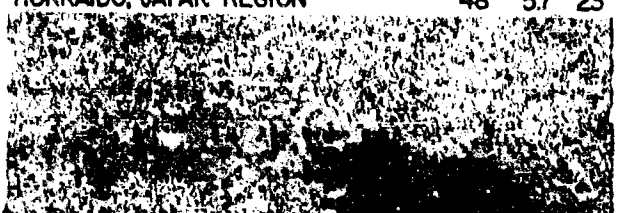
22 FEB 67   16 24 39.1   41.6N   139.7E
HOKKAIDO, JAPAN REGION   176   5.4   30
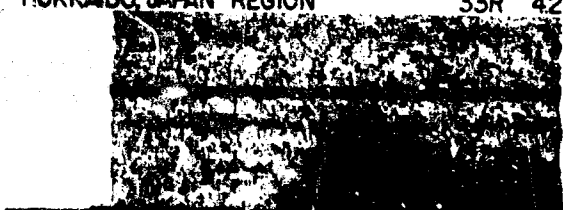
20 JUN 68   18 12 25.3   41.4N   142.6E
HOKKAIDO, JAPAN REGION   50   4.6   23
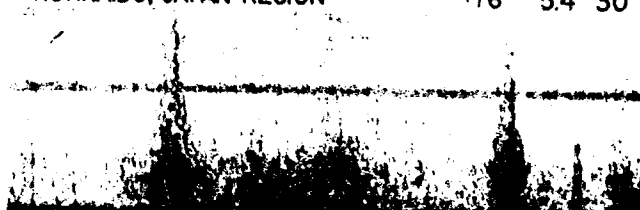
01 MAY 68   19 16 39°   40.9N   142.4E
NEAR EAST COAST OF HONSHU, JAPAN   45   4.7   24

18 JUN 68   17 10 41.8   41.4N   142.5E
HOKKAIDO, JAPAN REGION   34   4.6   34

16 MAY 68   00 48 55.4   40.8N 143.2E
OFF EAST COAST OF HONSHU, JAPAN   7 7.9 24

02 MAY 68   05 38 48.8   40.7N 142.8E
NEAR EAST COAST OF HONSHU, JAPAN   43 46 35

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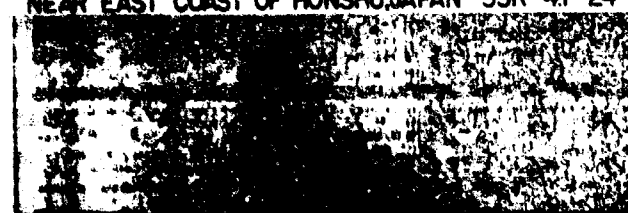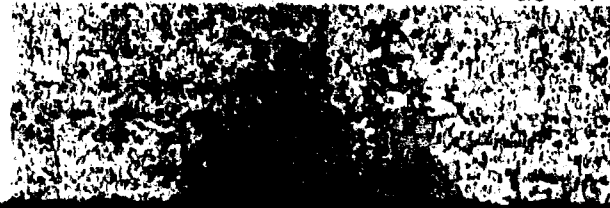OFF EAST COAST OF HONSHU, JAPAN 45 4.3 24

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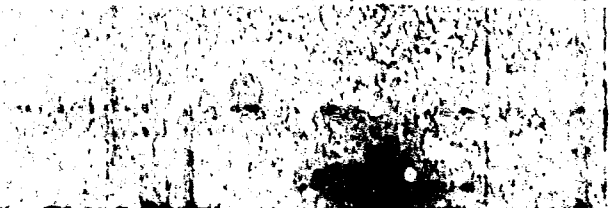
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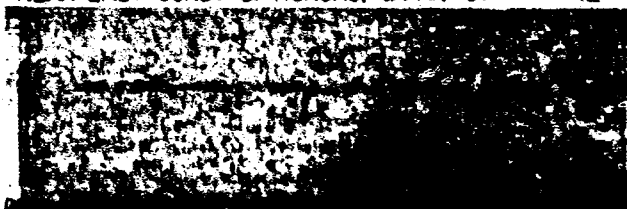
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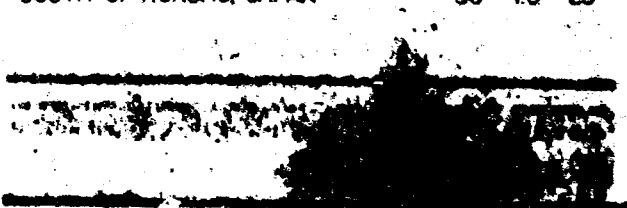
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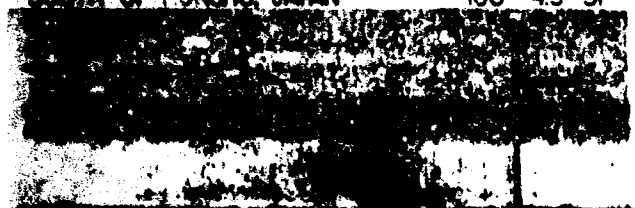
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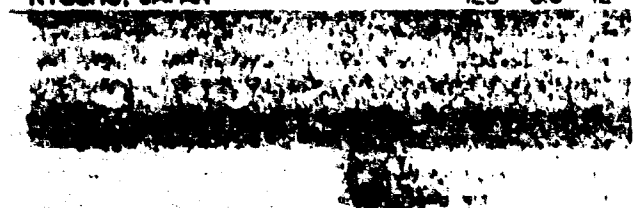
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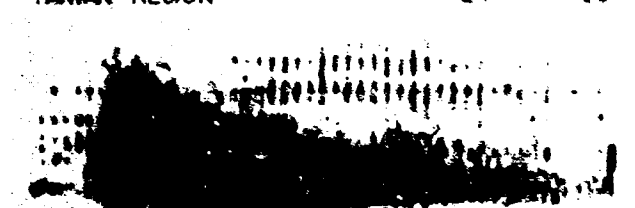
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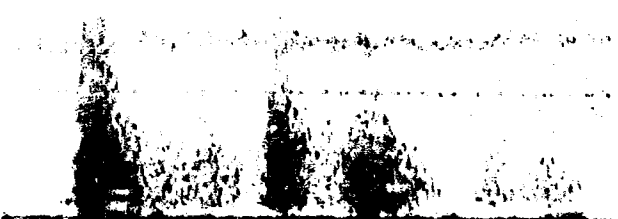
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29 JAN 68   16 00 07.3   12.3N 125.5E
SAMAR, PHILIPPINE ISLANDS   51 5.3 24

12 JUN 68   20 15 47.8   0.6S 132.8E
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BONIN ISLANDS REGION   40 4.6 32

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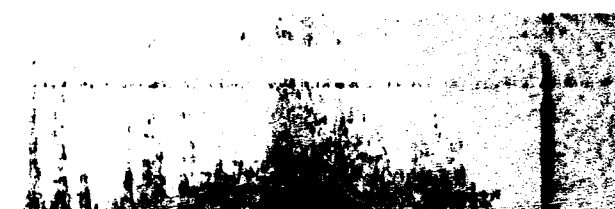
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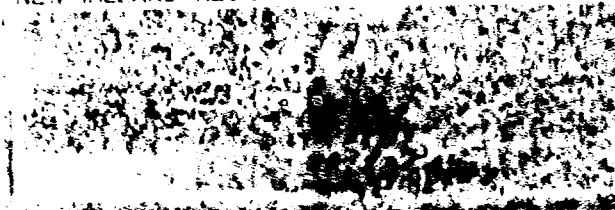
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NEW IRELAND REGION   32

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SOUTH OF MARIANA ISLANDS   33   51 32

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| DEC 67 | 04 28 21* | 5.0S | 153.7E |
| NEW IRELAND REGION | | 130 | 4.9 | 37 |

| 29 MAR 64 | 21 40 32.7 | 6.7S | 155.1E |
| SOLOMON ISLANDS | | 68 | 5.3 | 44 |

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| 04 OCT 67 | 17 21 20.7 | .S | 153.9E |
| NEW IRELAND REGION | | 52 | 7 | 32 |

| 18 APR 68 | 12 49 33* | 6.9S | 156.0E |
| SOLOMON ISLANDS | | 167 | 5.1 | 32 |

| 21 JAN 68 | 00 28 12.5 | 5.2S | 154.0E |
| SOLOMON ISLANDS | | 113 | 5.1 | 23 |

| 17 OCT 65 | 01 53 33.7 | 8.0S | 156.3E |
| SOLOMON ISLANDS | | 20 | 5.6 | 34 |

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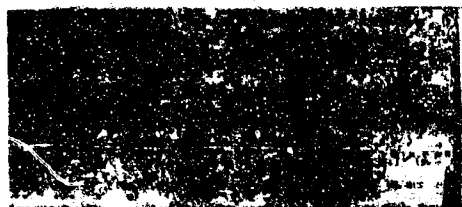15 SEP 63   00 46 54.1   10.3S   165.6E
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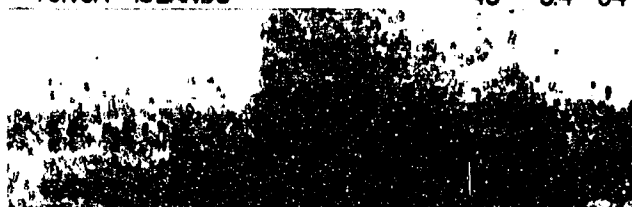
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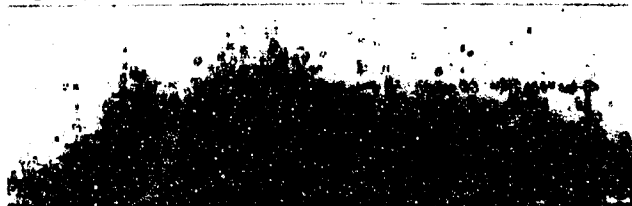
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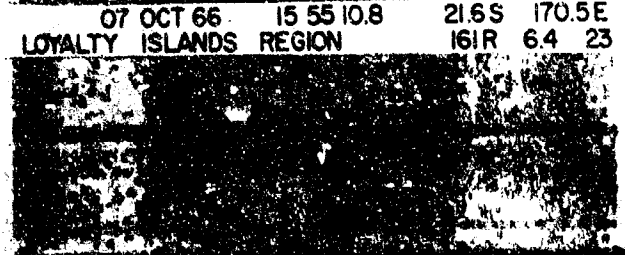
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TONGA ISLANDS   52   4.6   43

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13. ABSTRACT

The transformation of earthquake body waves to T waves is as efficient at deep slopes as at slopes which transect the sofar axis. Moreover, spectral studies of T phase signatures have shown no basis for distinguishing between the two cases. As simple downslope propagation is inadequate to explain the production of T waves at deep slopes, that process is relegated a minor role in favor of scattering from the sea floor as the dominant mechanism. A slope in the direction of propagation insures that once energy is scattered in that direction the probability of it being unfavorably rescattered upon successive approaches to the sea floor will be less. Scattering near the sea surface is detectable in the absence of bottom-scattered T waves. Such abyssally generated T waves display a distinctly higher frequency spectrum when originating in subarctic regions than when originating in lower latitudes. This difference is ascribed to downward ducting of higher frequency energy from the subarctic surface channel.

DD FORM 1473
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	ROLE	WT	ROLE	WT	ROLE	WT
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